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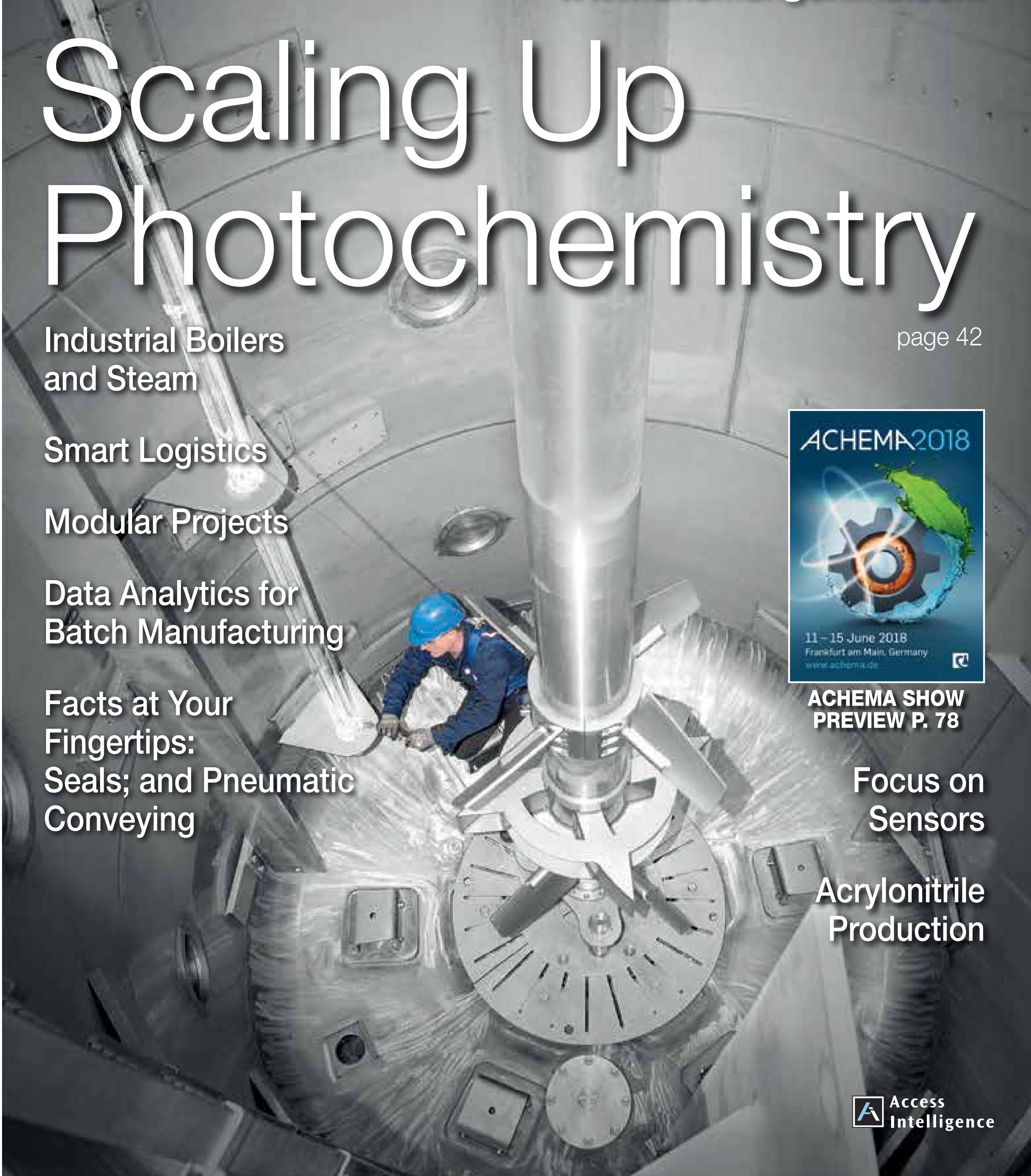

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Cover Story

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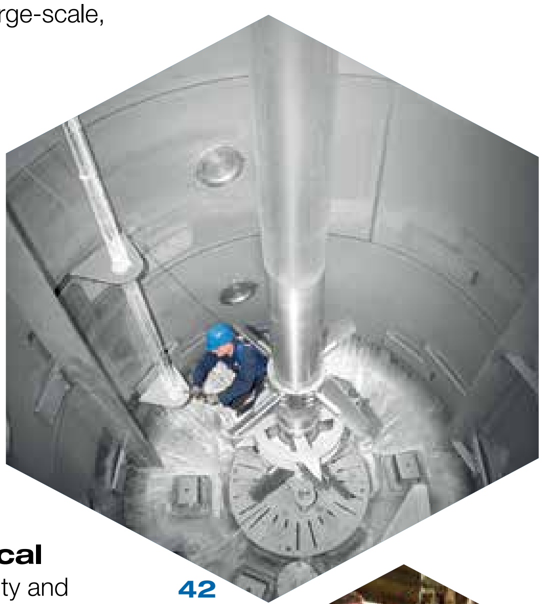
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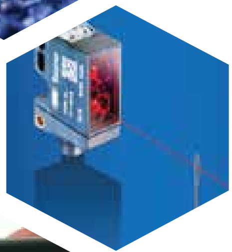

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CHEMICAL ENGINEERING
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Editor's Page

Embracing a circular economy

Last month, for the first time, U.S. plastic resin producers publicly committed to measurable targets toward complete recovery and recycling of plastic packaging. The American Chemistry Council's (ACC; www.americanchemistry.com) Plastics Division, which includes 15 of the leading resin manufacturers, announced the following ambitious goals: 1) 100% of plastics packaging is recyclable or recoverable by 2030; and 2) 100% of plastics packaging is re-used, recycled or recovered by 2040.

To reach these ambitious goals, the division outlined the following six focal areas in its announcement: 1) design of new products for greater efficiency, recycling and reuse; 2) new technologies and systems development for collecting, sorting, recycling and recovering materials; 3) simplification for more consumers to participate in recycling and recovery programs; 4) expansion of the types of plastics collected and repurposed; 5) product alignment with key end-markets; and 6) increased awareness that used plastics are valuable resources.

A global issue

A study reported in July of last year in *Science Advances* (www.advances.sciencemag.org/content/3/7/e1700782.full) states that as of 2015, only around 9% of plastic waste had been recycled and 79% was accumulated in landfills or the natural environment. Plastic debris has been found in all of the oceans, and an estimated 4 to 12 million metric tons of this debris entered the marine environment in 2010 alone.

In its current June issue, *National Geographic* magazine (www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis) brings awareness to the environmental impact of plastics, and in particular to the marine environment. The striking images in the article emphasize the findings of the report. ACC's vice president of plastics, Steve Russell, commented on the article, saying "Marine litter is a serious global problem, and we appreciate *National Geographic*'s thoughtful and compelling coverage."

And this month, sustainability and recycling will be a focal topic at the Polyethylene-Polypropylene Chain Global Technology & Business Forum (www.ihsmarkit.com) in Düsseldorf, Germany. While demands for plastics are growing, so are consumer expectations for sustainability. According to Nick Vafiadis, vice president of plastics for IHS Markit (the host of the forum), "The issue of sustainability is perhaps the most critical influencer for the plastics industry as a whole, both today and in the future."

Supporting technologies

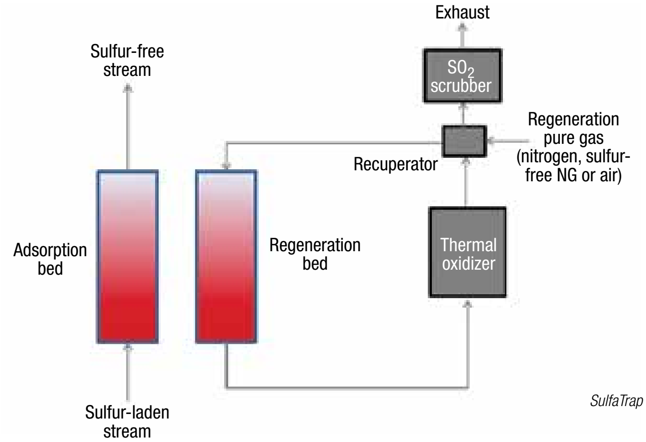
Developing and existing technologies are poised to support the move toward a circular economy. For example, in April, Agilyx (www.agilyx.com) began polystyrene recycling operations, said to be the world's first commercial-scale closed-loop chemical recycling process. And numerous companies, such as Vadxx (www.vadxx.com) and Greenmantra (www.greenmantra.com), are working on creating value from waste plastics.* The goals announced by the ACC Plastics Division and the worldwide efforts to move away from a linear economy with disposal as an end result, to a circular economy with reuse and recycling, are welcome initiatives that can ultimately benefit us all. ■

Dorothy Lozowski, Editor in Chief

*For more, see our report on "Advanced Polymer Recycling" (*Chem. Eng.*, March 2014; www.chemengonline.com/advanced-polymer-recycling).

Highly selective adsorbent tackles complex sulfur species

To meet strict sulfur specifications and reduce emissions, amine scrubbing and caustic treatment are frequently used to remove hydrogen sulfide from gas and liquid streams, but these methods are not effective for handling more complex organo-sulfur compounds, such as thiophenes and disulfides. SulfaTrap LLC (Arvada, Colo.; www.sulfatrap.com) has developed a new adsorbent consisting of highly dispersed base metals that uses unique surface groups to remove sulfur species via strong molecular interactions. These interactions are two to three times greater than those observed with typical physical adsorbents that remove sulfur species via Van der Waals forces, enabling a higher selectivity for a larger range of sulfur species, even in the presence of moisture or unsaturated hydrocarbons, according to Gokhan Alptekin, managing director of SulfaTrap. "Because these surface sites do not bind the sulfur through a covalent bond, it is easy to regenerate the sorbent and release the adsorbed sulfur groups from the surface by applying a relatively small change in the chemical potential. The process utilizes a mild temperature swing to regenerate the sorbent with very high energy efficiency," explains Alptekin.



The operation of SulfaTrap's process (diagram) is very similar to that of molecular-sieve zeolites used in regenerable dehydration applications. A minimum of two sorbent vessels are used; one bed is in operation while the other is regenerated. Sorbent regeneration involves raising the bed temperature by 250°C and a warm purge-gas stream supplies heat to the beds. Captured sulfur compounds are recovered and oxidized into SO_2. The technology has been piloted at four demonstration sites, the largest for a 75-barrel-per-day mixed-butane stream.

"We have shown the efficacy of the technology in desulfurizing C4 mixtures, C4–C8 condensates and bioethanol, as well as high-value biochemicals, such as alpha pinene," says Alptekin. He mentions that with minor setup modifications, the system can also be used to treat natural gas and biogas. SulfaTrap expects to deliver its first commercial-scale system in early 2019.

Harnessing the Joule-Thomson effect

A thermal-membrane process system, based on the Joule-Thompson effect (JTE) for treating wastewater with high salinity or with a high-level of inorganic contents has been developed by Thermosift Engineering Pvt. Ltd. (Asaripallam, Tamil Nadu, India; www.thermosift.com). The system operates at relatively low pressure and temperature compared with the conventional thermal-based separation processes. Other advantages are a very high water recovery at a minimum energy consumption, small footprint and minimum capital cost compared with the conventional thermal separation systems, says the company.

Called TS-30, the system is capable of producing up to 30 L of water per square meter of membrane. The company has also developed the Stomat vapor-transfer membrane for high strength industrial effluent treatment, desalination and heat- and mass-transfer processes.

The TS-30 system uses the microporous Stomat membrane as a JTE "throttling device," which functions as the porous plug or the expansion valve. This JTE process helps increase the mass transfer due to heat loss and the company's product design helps to recover the heat, which in turn improves the thermal efficiency of the entire TS-30 system.

Recently, the company successfully completed a test run of its TS-30 system for treating the salty effluent of a hydrometallurgical process with a European partner. The system helped treat the highly saline (total dissolved solids of 35,000 to 350,000 parts per million) water and recover valuable inorganic salt from the process.

Edited by:
Gerald Ondrey

C_2H_2 HYDROGENATION

Last month, Clariant (Munich, Germany; www.clariant.com) launched OleMax 260, a new selective acetylene-hydrogenation catalyst, which is said to have extremely high ethylene selectivity and operational stability. Specially developed for ethylene producers with "front-end" process configurations, OleMax 260 offers a "near perfect selectivity to ethylene (close to 100%), resulting in significant economic benefit for the operator," says Clariant. The catalyst has ultra-high stability, which impedes thermal runaway reactions that can lead to unplanned production outages. The exceptional selectivity and consequent stability of OleMax 260 ensures reliable, on-specification performance over an unprecedentedly wide operating range, even at the extremely low CO levels typical of new cracking furnace technologies, the company adds. The catalyst's simplified streaming procedure significantly reduces normal startup-related hydrocarbon flaring and time to on-specification ethylene production.

OleMax 260 is optimized to operate in de-ethanizer overhead hydrogenation process configurations. It can be used in a new build or as a drop-in solution in an existing facility.

The first commercial application of OleMax 260 is at the new ethylene-production plant of The Dow Chemical Company in Freeport, Texas, operating since Q3 2017.

STRONG BIOFIBERS

Researchers at the KTH Royal Institute of Technology (Stockholm, Sweden; www.kth.se) have produced a bio-based material that is reported to surpass the strength of all known bio-based materials, whether

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fabricated or natural. Measurements of the material, reported last month in *ACS Nano*, have been found to have a Young's modulus (tensile stiffness) of 86 GPa and a tensile strength of 1.57 GPa. "The bio-based nanocellulose fibers fabricated here are eight times stiffer and have strengths higher than natural dragline spider silk fibers, generally considered to be the strongest bio-based material," says Daniel Söderberg, researcher at KTH Royal Institute of Technology, and corresponding author of the study. "The specific strength is exceeding that of metals, alloys, ceramics and E-glass fibers."

Macroscopic fibers of cellulose nanofibrils (CNFs) are fabricated by flow-assisted organization of the fibrils, using a double-focusing channel. By controlling the flow of CNFs suspended in water, with connecting flows of deionized water and low-pH water, the CNFs become aligned in the right direction, and enable the supramolecular interactions between CNFs to self-organize into a well-packed state where they are joined together.

Söderberg says the study opens the way for developing nanofiber material that can be used for larger structures while retaining the nanofibers' tensile strength and ability to withstand mechanical load. The process can also be used to control nanoscale assembly of carbon tubes and other nano-sized fibers.

TURING PATTERNS

A research team, led by Lin Zhang, professor of biomass chemical engineering at Zhejiang University (Hangzhou, China; www.zju.edu.cn), has fabricated polyamide membranes with nano-scale Turing structures, which makes them more efficient than conventional desalination membranes used in reverse osmosis (RO) systems. Turing structures or patterns are named after English scientist Alan Turing, who in the 1952

(Continues on p. 9)

First bio-based FDME pilot plant opens

DuPont/ADM

The world's first pilot plant for manufacturing bio-based furan dicarboxylic methyl ester (FDME) began operating last month in Decatur, Ill.

A collaboration between DuPont Industrial Biosciences (Wilmington, Del.; www.biosciences.dupont.com) and Archer Daniels Midland Co. (ADM; Chicago, Ill.; www.adm.com), the 60-ton/yr pilot facility represents the next step in an ongoing commercialization process for bio-based FDME (see *Chem. Eng.*, March 2016, p. 9).

Bio-based FDME is made from cornstarch-derived fructose starting material, and will be used to make a range of bio-based chemicals and plastics. The fructose is dehydrated and the products from the reaction are oxidized to form furan dicarboxylic acid (FDCA). The FDCA is then reacted with methanol, resulting in FDME. DuPont and ADM say plastics derived from bio-based FDME will ultimately be more cost-effective, efficient and sustainable than their petroleum-based counterparts.

One of the first FDME-based polymers under development by DuPont is polytrimethylene furandicarboxylate (PTF), a novel polyester also made from DuPont's proprietary Bio-PDO (1,3-propanediol). PTF is a 100% renewable polymer, DuPont and ADM say, that, in bottling applications, can be used to create plastic bottles that are lighter-weight, more sustainable and better performing. Research by the two companies shows that PTF has up to 10–15 times the CO_2 barrier performance of traditional PET (polyethylene terephthalate) plastic, which results in a longer shelf life. Improved barrier performance could allow lighter-weight packaging designs for beverages.

The two companies say they hope to further scale up the FDME production process in the coming months.

DeNOx catalyst operates at lower temperatures

Professor Toru Murayama at Tokyo Metropolitan University (Tokyo, Japan; www.haruta-masatake.ues.tmu.ac.jp), in collaboration with Chugoku Electric Power Co., Inc., has developed a vanadium oxide catalyst that removes oxides of nitrogen (NOx) from fluegas generated by the combustion of heavy fuel oil and coals. The developed V_2O_5 catalyst has a high specific-surface area of 40 m^2/g, which enables the deNOx reaction to take place at a temperature of around 150°C. This is considerably lower than the 400°C required by existing catalysts (0.5–2 wt.% V_2O_5, with surface areas of 2.5 m^2, deposited on a TiO_2 system). The lower temperature operation is also expected to enable the catalyst to have a longer lifetime, thereby lengthening the time required for changeout. Conventional catalysts operating at the higher temperatures need to be changed every 2–4 years, which costs several million dollars per changeout, says Murayama.

The new catalyst is fabricated to have a large surface area by calcination of ammonium metavanadate precursor with oxalic acid. The catalyst is composed solely of V_2O_5, and shows a 90% selectivity for the reduction of NOx. It is suitable for low-temperature deNOx of fluegas when poisons, such as sulfur dioxide, have first been removed. So far the researchers have demonstrated that the catalytic performance is unchanged after treating fluegas for 7 days. They are now planning to perform durability testing at a coal-fired power plant through 2021, with commercial applications by 2024. Besides power plants, the catalyst may also be suitable for treating the exhaust from incinerators, as well as helping ships to meet the tighter international-maritime regulations.

This wallpaper has built-in fire detection

Researchers from the Chinese Academy of Sciences (Beijing, China; www.cas.cn), led by professor Ying-Jie Zhu, have reported a "smart" fire-alarm wallpaper prepared using ultralong hydroxyapatite nanowires and graphene oxide thermosensitive sensors. At room temperature, the graphene-oxide sensor is an electrical insulator, but it becomes electrically conductive at high temperatures. In case of fire, high temperature will quickly remove the oxygen-containing groups of graphene oxide, causing an alarm to be sent out. After surface modification of graphene oxide with polydopamine, the sensitivity and flame retardancy of the sensor are further improved, resulting in a low-temperature fast response and sustained working time in a flame (at least 5 min.).

Hydroxyapatite, $Ca_{10}(OH)_2(PO_4)_6$, is the major inorganic component of bone and teeth in vertebrates, and has been investigated for biomedical applications. However, hydroxyapatite materials are usually brittle because they form particles, short rods or needles. The team has found that ultralong hydroxyapatite nanowires with ultrahigh aspect ratios have high flexibility and can solve the problems of brittleness and poor flexibility.

According to the team, ultralong hydroxyapatite nanowires are a promising biomaterial with advantages such as high biocompatibility, high flexibility, good mechanical properties, high thermal stability, and fire resistance. Therefore, the nanowires are said to be excellent building materials for the construction of flexible fire-resistant inorganic paper. The smart fire-alarm wallpaper can be processed into various shapes, dyed with different colors, and printed with a commercial printer and thus can be used in high-safety interior decoration of homes.

predicted that two chemical substances, activator and inhibitor, can, under certain conditions, react and diffuse with each other to generate spatiotemporal stationary structures, which are responsible for the stripes of a zebra, the spiral of a snail or the markings on leaves.

The new membranes are made by a process based on interfacial polymerization, where the reactions occur at the interface between oil and water layers. The addition of polyvinyl alcohol to the aqueous phase reduced the diffusion of the monomer. This process — described in the May 4 issue of *Science* — generated membranes with more bumps, voids and islands, which prove to be better for water desalination.

Microscopic characterization of the Turing-type membranes reveals that the spatial distribution of relatively higher-water-permeability sites agrees well with the corresponding Turing structures at the nanoscale. These unusual nanostructures, which are generated by diffusion-driven instability, enable outstanding transport properties in both water permeability and water-salt selectivity.

BIOBUTANOL

Biobutanol offers great promise as a gasoline substitute because of its high energy density (29.2 MJ/L for butanol versus 19.6 MJ/L for ethanol and 32 MJ/L for gasoline). Traditional

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biofuels are produced from crops, competing with food production in the use of resources. Currently, bioconversion of cellulose to biofuels requires several steps, including pretreatment, enzymatic saccharification, detoxification and fermentation. It is therefore desirable to develop a bioconversion technology for the direct conversion of cellulosic biomass into biofuels without the need for those pretreatment steps.

Now, a team from the National University of Singapore (www.nus.edu.sg), led by professor He Jianzhong has found that a naturally occurring bacterium — *Thermoanaerobacterium thermosaccharolyticum* strain TG57, isolated from waste generated after harvesting mushrooms — is capable of directly converting cellulose to biobutanol. The TG57 strain evolves naturally in the waste generated by mushroom farming — typically wheat straw and saw dust. The fermentation process is simple and requires no pretreatment or genetic modification of the bacteria. The TG57 strain uses microcrystalline cellulose directly to produce butanol (1.93 g/L) as the only final product, without generating side products acetone or ethanol.

MOLTEN SALT CSP

Thanks in large part to developing and operating a facility for testing molten salt reactor (MSR) technologies, nuclear experts at Oak Ridge National Laboratory (ORNL; Tenn.; www.ornl.gov) are now tackling the next generation of another type of clean energy — concentrating solar thermal power (CSP). The U.S. Energy Dept.'s Solar Energy Technologies Office selected the ORNL-based team to develop a molten chloride salt facility as part of the Generation 3 Concentrating Solar Power Systems (Gen3 CSP) program. The Gen3 CSP program supports research in materials and facilities that could allow future CSP plants to operate at higher temperatures and lower the cost of electricity production.

Kevin Robb, a staff scientist in ORNL's Reactor and Nu-

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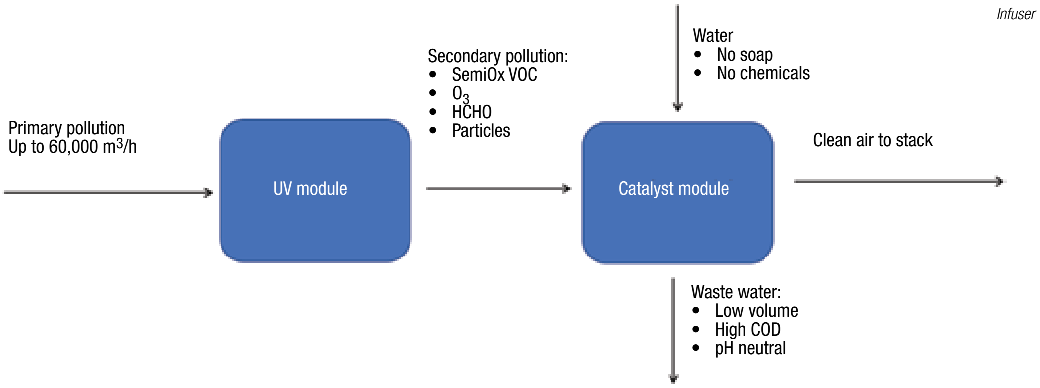
Taking UV/O_3 VOC treatment one cleaner step forward



Using ultraviolet (UV) radiation or ozone (or both) to oxidize air pollutants, such as volatile organic compounds (VOCs) is a well-established treatment method in the chemical process industries (CPI). What is not so well known, however, is that for most pollutants, the oxidation products of UV/O_3 treatment, such as O_3, formaldehyde and a whole range of other semi-oxidized compounds, can be significantly more hazardous than the original VOC, says Nicolai Bork, product manager – Industrial Pollution Control at Infuser ApS (Copenhagen, Denmark; www.infuser.eu). "Alarmingly, we see many installations using just UV/O_3 where factory owners have never been informed about these issues."

Infuser has taken conventional UV/O_3 technologies a step further by incorporating a catalytic filter to the normal UV-treatment section. Developed in close collaboration with the University of Copenhagen, the company's Climatic air-purification technology (diagram) is based on accelerating the self-cleansing mechanisms of the atmosphere — namely, a carefully adjusted combination of gaseous oxidants, water vapor and UV light, explains Bork. This produces OH radicals that oxidize VOCs into oxidation products (OxVOCs) that precipitate out of the gas phase as aerosol particles. A second-stage treatment, using a multibed O_3-removal catalyst with VOC-adsorption capabilities, performs O_3 removal and oxidation of the semi-oxidized VOCs to CO_2. Furthermore, the filter is designed to capture the produced aerosol particles. For industrial applications, an automated washing of the filter medium can be installed for large-scale continuous operation, he says.

Conventional cleaning technologies, such as adsorption on activated carbon have pressure drops that are 10–15 times higher that a Climatic system, which can translate to 20–100 kW of saved energy for fan power alone, says Bork.

The process has been demonstrated at a leading wind-turbine OEM factory in Europe, which started up in 2017. Four units, totalling 210,000 m^3/h, have been continuously reducing styrene emissions by more than 90%, while saving the operator "significant costs" of replacing activated carbon. The company is also targeting other applications in the styrene and polymer industries, says Bork.

A Pt-free electrode for making H_2 from water

One of the major obstacles to making hydrogen economically by splitting water is the high cost of noble-metal electrodes. Less expensive, non-noble metals only function as electrocatalysts under alkaline conditions, where the reaction requires more electricity.

Now, professor Ryoichi Ito at the University of Tsukuba (Tsukuba City, www.tsukuba.ac.jp), in collaboration with Osaka University and Tohoku University, has developed non-noble-metal electrodes capable of performing the H_2-evolution reaction (HER) as efficiently as conventional Pt/C electrodes, even under acidic conditions. The new electrodes use nitrogen-doped graphene sheets to encapsulate a NiMo alloy electrode. Unlike other graphene-based electrodes, the Tsukuba system incorporates nanometer-sized holes, which are ringed by chemically active ridges known as fringes. These fringe defects are more hydrophillic than normal graphene, so they attract H_3O^+ ions in the acid solution, which are involved in the HER reaction mechanism. The fringes also adsorb H atoms, thereby providing extra surface area for another HER process. As a result, the H_2 is generated as efficiently as with the more expensive Pt/C electrode, and the remaining hole-free part of graphene protects the metals from corroding in the acid. The research is described in a recent issue of *ACS Catalyst*.

Biologically inspired denitrification catalyst

The development of denitrification catalysts that can reduce nitrate and nitrite to N_2 is critical for sustaining the nitrogen cycle. However, regulating the catalytic selectivity has proven to be a challenge, due to the difficulty of controlling complex multi-electron/proton reactions. Now, Ryuhei Nakamura and coworkers at Riken (Wako City, Japan; www.riken.jp) have developed an artificial catalyst that imitates the denitrification enzyme of microorganisms, and succeeded in converting nitrite ions efficiently into harmless N_2.

The researchers focused on the microorganisms that perform multi-step reactions under mild conditions using four enzymes that contain metals, such as Fe, Cu and Mo as the active center of the enzyme. They found that the catalyst composed of the enzyme containing Mo as the active center of the enzyme in the shape of a pterin-like structure, coordinated with the oxygen and sulfur, efficiently detoxifies the nitrite ions into N_2 under mild conditions and without using a large-scale drainage treatment installation. Using a hydrothermal synthesis method, they fabricated the catalyst with the pterin-like structure and confirmed that this catalyst contained a MoS_4 structure similar to the active site of the enzyme.

They also showed that utilizing sequential proton–electron transfer (SPET) pathways is a viable strategy to enhance the selectivity of electrochemical reactions. The selectivity of an oxo-molybdenum sulfide electro-catalyst toward nitrite reduction to dinitrogen exhibited a volcano-type pH dependency with a maximum at pH 5. The pH-dependent formation of the intermediate species (distorted Mo(V) oxo species), identified using operando electron paramagnetic resonance (EPR) and Raman spectroscopy, was in accord with a mathematical prediction that the pKa of the reaction intermediates determines the pH-dependence of the SPET-derived product. By utilizing this acute pH dependence, they achieved a Faradaic efficiency of 13.5% for nitrite reduction to N_2, which is the highest value reported to date under neutral conditions. ■

clear Systems Division, will lead the investigation into a chloride salt CSP heat-transfer fluid. Robb's nuclear-focused research uses the Liquid Salt Test Loop, a one-of-a-kind test facility that heats fluoride salts to around 700°C, and then pumps the salts through the loop. The loop is helping researchers develop and analyze technologies that industry could one day use in fluoride salt-cooled high-temperature reactors, a type of MSR.

Robb and Gen3 CSP project collaborators from the University of Utah, Virginia Tech and Argonne National Laboratory will develop the solar-based loop, with salts and components different from those found in the Liquid Salt Test Loop.

The facility will operate at temperatures above 725°C. This increased temperature will increase the efficiency of heat-to-electricity conversion to provide an economic advantage over current CSP systems that normally operate below 600°C. The end result could be a CSP system with greater electricity output at lower costs. This work could put the solar industry closer to reaching DOE's goal of reducing the cost of CSP energy to $0.05/kWh by 2030. ❑

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Plant Watch

Total and Sonatrach begin engineering studies for joint petrochemicals project

May 11, 2018 — Total S.A. (Paris, France; www.total.com) and Sonatrach (Algiers, Algeria; www.sonatrach.com) will launch engineering studies for a petrochemical project in Arzew, Algeria. The project includes a propane dehydrogenation unit and a polypropylene production unit with a capacity of 550,000 metric tons per year (m.t./yr). The project represents an investment of around \$1.4 billion by the two partners, who are planning to start front-end engineering and design (FEED) this summer.

Eastman plans copolyester capacity expansion

May 10, 2018 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) intends to expand production capacity for copolyester products at its Kingsport, Tenn. manufacturing site. The expansion is expected to be complete in the third quarter of 2018 and will increase polyethylene terephthalate glycol (PETG) and polycyclohexylenedimethylene terephthalate glycol (PCTG) capacities by approximately 25%.

Showa Denko completes NPAC capacity expansion

May 8, 2018 — Showa Denko (SDK; Tokyo; www.sdk.co.jp) has completed a production expansion for *n*-propyl acetate (NPAC) at its Oita Complex. In 2016, SDK increased the production capacity of the NPAC plant to 16,000 m.t./yr and now has further expanded the capacity of the plant to 18,200 m.t./yr of NPAC.

Invista to provide fourth PTA process technology license for Hengli

May 3, 2018 — Invista (Wichita, Kan.; www.invista.com) and Hengli Petrochemical Co. have reached an agreement to license Invista's latest purified terephthalic acid (PTA) process technology for Hengli's fourth PTA line. The fourth PTA line will have a design capacity of 2.5 million m.t./yr, and will be installed at Changxing Island, Liaoning Province, China.

Celanese adds new production line in Nanjing for ultra-high molecular weight PE

May 2, 2018 — Celanese Corp. (Dallas, Tex.; www.celanese.com) announced the addition of a new ultra-high molecular weight polyethylene (UHMW-PE) production line at its Nanjing, China manufacturing facility. The new line is expected to add around 15,000 m.t./yr of UHMW-PE product capacity by 2019.

Arkema starts up expanded PVDF unit in Kentucky

April 26, 2018 — Arkema (Colombes, France; www.arkema.com) successfully brought on stream new Kynar PVDF (polyvinylidene difluoride) capacity at its Calvert City, Kentucky plant. The expansion represents a 20% increase in Arkema's U.S. production capacity.

Jacobs wins services contract for Encina's BTX plant in Wyoming

April 26, 2018 — Jacobs Engineering Group Inc. (Dallas, Tex.; www.jacobs.com) received a contract from Encina Chemicals, LLC (Coral Gables, Fla.; www.encina.com) to provide operations readiness support services for Encina's new benzene-toluene-xylenes (BTX) processing plant in Gillette, Wyoming. When commissioned in the summer of 2020, this plant will feature a scalable design to produce 50,000 to 100,000 m.t./yr of BTX.

Wacker opens new production site for silicones in South Korea

April 25, 2018 — Wacker Chemie AG (Munich, Germany; www.wacker.com) opened a new production site for silicone elastomers in Jincheon, South Korea. Wacker already has an established production base in Jincheon, where the group has been producing silicone sealants and specialty silicones since 2010. Around €15 million has been invested in the new 13,000-m^2 production site.

Air Liquide doubles its global biomethane production capacity

April 20, 2018 — Air Liquide (Paris, France; www.airliquide.com) has commissioned three new biomethane production units in Walnut, Miss., Cestas, France and Northwick, U.K. With these units, Air Liquide has doubled its biomethane production capacity. Air Liquide has invested around €100 million in biomethane production in recent years.

Toray to establish resin production plant in India

April 18, 2018 — Toray Industries, Inc. (Tokyo, Japan; www.toray.com) plans to establish a production facility for nylon and polybutylene terephthalate (PBT) resin compounds at its Indian subsidiary, TID. The facility, which will have a production capacity of 5,000 m.t./yr, will be set up at TID's base in Sri City in Andhra Pradesh State, and the company is aiming to start operations in September 2019.

Mergers & Acquisitions

ExxonMobil agrees to sell petroleum refinery in Sicily to Sonatrach

May 10, 2018 — Sonatrach signed an agreement with ESSO Italiana, a subsidiary of Exxon Mobil Corp. (Irving, Tex.; www.exxonmobil.com) for the purchase of ExxonMobil's refinery located in Augusta, Sicily, Italy, as well as three oil terminals located in Italy and their associated

pipeline systems. The transfer of the refinery and its assets to Sonatrach will take place at the end of 2018.

BASF and Solenis to merge paper and water chemicals businesses
May 3, 2018 — Solenis (Wilmington, Del.; www.solenis.com) and BASF SE (Ludwigshafen, Germany; www.basf.com) signed an agreement to combine BASF's paper and water chemicals business with Solenis to jointly create a global specialty chemicals company. The combined company intends to operate under the Solenis brand and will provide expanded offerings for paper and industrial water technologies. The transaction is expected to close around the end of 2018.

Marathon Petroleum to purchase Andeavor for $35.6 billion
May 2, 2018 — Marathon Petroleum Corp. (MPC; Findley, Ohio; www.marathonpetroleum.com) and Andeavor (San Antonio, Tex.; www.andeavor.com) have entered into a definitive merger agreement under which MPC will acquire all of Andeavor's outstanding shares, representing a total enterprise value of $35.6 billion. With a capacity of over 3 million bbl/d, the combined company will be the largest refiner in the U.S.

ExxonMobil to acquire lubricant manufacturer in Indonesia
May 1, 2018 — ExxonMobil agreed to purchase PT Federal Karyatama (FKT), one of Indonesia's largest manufacturers of lubricants. The acquisition includes the Federal Oil brand and a 700,000-bbl/d blending plant in Cilegon, Indonesia. ExxonMobil expects the transaction to close in the third quarter of 2018.

CarbonCure and Airgas to collaborate on CO_2 utilization
May 1, 2018 — CarbonCure Technologies Inc. (Halifax, N.S., Canada; www.carboncure.com) will collaborate with Airgas (Radnor, Pa.; www.airgas.com) to enhance the adoption of CO_2-utilization technologies in the cement and concrete industries throughout the U.S. Gulf Coast region. CarbonCure's technology injects CO_2 sourced from industrial sites into concrete, where the CO_2 becomes mineralized.

Italmatch acquires metalworking fluids business from Afton
April 27, 2018 — Italmatch Chemicals Group (Genova, Italy; www.italmatch.com) agreed to acquire the metalworking fluid business (formally known as Polartech) from Afton Chemical (Richmond, Va.; www.aftonchemical.com). The deal includes sites in Bedford Park, Ill. and Manchester, U.K., as well as technology, production and business activities in Hyderabad, India and China.

AkzoNobel and Ineos to collaborate on chelates production
April 20, 2018 — AkzoNobel Specialty Chemicals (Amsterdam, the Netherlands; www.akzonobel.com) and Ineos (Rolle, Switzerland; www.ineos.com) have signed a cooperation agreement that will allow AkzoNobel to expand its production of biodegradable chelates, utilizing one of Ineos Nitriles' chemical products. With this partnership, AkzoNobel will expand its chelates production in Europe with the construction of new production facilities in Cologne, Germany, which Ineos will operate. These new facilities are slated for completion in 2020. ■

Mary Page Bailey

Transformations in Transit: Chemical Logistics Get Smarter

Digitalization, sustainability, security and safety are at the forefront of innovations in the logistics and supply-chain sectors

IN BRIEF

- SUPPLY-CHAIN SAFETY AND SECURITY
- DIGITAL EVOLUTION
- BATTERIES POWER EFFICIENCY
- SUPPLY-CHAIN SUSTAINABILITY

Ensuring that chemical products reach the correct location at the correct time requires intricate networks of complex logistics and scheduling tasks where several entities may hold a stake. Users are beginning to reap the efficiency benefits of adopting advanced automation technologies to streamline logistics activities, but concerns about security, infrastructure and an aging workforce remain.

Honeywell

FIGURE 1. New track-and-trace capabilities enable precise monitoring of a shipment, pallet or even an individual item

Supply-chain safety and security

As with chemical manufacturing, safety and security measures play a crucial role once the product leaves the plant to be transported to a distributor or customer. For this reason, chemical distributors must work closely with government agencies to ensure proper oversight is taken to protect personnel and product integrity. In April, representatives from the National Association of Chemical Distributors (NACD; Arlington, Va.; www.nacd.com) visited Washington, D.C. to promote reauthorization of the Chemical Facility Antiterrorism Standards (CFATS) program, as well as advocate for freight rail reform. NACD has worked closely with the U.S. Department of Homeland Security on the CFATS program, which was first launched in 2007. "CFATS looks directly at chemical risk, and management of that risk," says Douglas Brown, chairman of NACD and president of Brown Chemical Co. (Oakland, N.J.; www.brownchem.com). CFATS is predominantly oriented toward fixed chemical sites, but also requires facilities that transport any of the over 300 chemicals of interest regulated by CFATS to address chemical security issues. "CFATS enhances the safety envelope of the chemical industry from manufacturers down to distributors," says Brown. NACD has also established its own program to address security and safety issues, Responsible Distribution. One element the program focuses on is carrier selection, which considers how to qualify third-party providers. "This has helped make the transportation of chemicals much safer over time," Brown adds.

Driven by the lack of responsiveness on the part of the rail sector, NACD is pushing for better customer service and cost competitiveness from rail providers, explains Brown. Further compounding the rail-related concerns are several developments in the trucking sector that are impacting the trucking capacity available for chemical distribution. Typically, when distributors face issues with rail transport, they can turn to trucks as a reliable alternative. Now, however, as the trucking sector adjusts to new regulations designed to enhance safety and security, driver shortages are creating bottlenecks. "With the advent of more rigorous background-check requirements for truck drivers due to concerns about chemical safety and security, the result has been a decreased pool of available drivers," says Brown. Furthermore, in April, federal mandates took effect that require drivers to use electronic logging devices, which hold drivers to new levels of account-

ability. Finally, Brown states that the aging fleet of drivers and the difficulty in attracting new drivers into jobs that require the transport of potentially hazardous materials are putting further stress on chemical distributors. “Driver shortage is a big issue,” he adds.

Digital evolution

Beyond physical security, cybersecurity is increasingly important as connected devices become more ubiquitous in trucks, trains and warehouses. Advanced telemetry and smart GPS devices provide information to distributors about the location and status of their fleet, while radio-frequency identification (RFID) and advanced barcoding technologies are contributing to more connected warehouses. While the NACD has begun early discussions about the potential use of autonomous vehicles, Brown emphasizes that they have not yet developed any official positions on the topic. “There are just so many variables and hazard scenarios that require driver interaction. But I’d imagine at some point, autonomous trucks might be utilized within the yards of large facilities or moving trailers back and forth into position,” he adds.

Smart wearable devices and augmented reality are two emerging areas of development for the logistics sector. Honeywell Safety and Productivity Solutions (SPS; Fort Mill, S.C.; www.honeywellaidc.com) offers voice-directed systems integrated into headsets that guide personnel through a set of complex, standardized tasks on checklists for preventive maintenance or inspection work. “This replaces paper-based work, which is prone to human errors and inefficiencies. The voice system guides users through their tasks and ensures compliance with documented workflows,” says Bruce Stubbs, Honeywell SPS director of supply chain industry marketing. Augmented reality is an emerging technology just beginning to find a place in the logistics sector, but Stubbs says it is most applicable for training workers. “The supply chain cannot necessarily move much faster, so companies are looking for ways to increase throughput and efficiency. But improvement can only happen when work is measured and data captured,” he continues.

The adoption of advanced technologies is essential for producers of hazardous chemicals or sensitive pharmaceutical ingredients, since products must meet stringent quality benchmarks and companies must comply with frequently changing government regulations. “The pressures for better transparency, accuracy, productivity and safety are driving the need for greater connectivity in the supply chain,” says Stubbs. “In Europe, for example, manufacturers of pharmaceuticals and other controlled substances, like explosives, are required to accurately track their shipments throughout the entire supply chain. They need to document each time a shipment passes through various stages or changes hands,” he adds. Honeywell SPS has developed cloud-based track-and-trace plat-

HOYER Group

FIGURE 2. HOYER Group has expanded its onsite logistics activities for Covestro's Coatings Adhesives Specialties facilities in Shanghai

forms that enable companies to track products — from an entire pallet down to a single item (Figure 1). "Each item receives a unique identifier, which is scanned and documented at each point in the supply chain, and this information is accessed from the cloud via a mobile device," explains Stubbs. And when sensitive pharmaceutical products are transported, the truck itself can be monitored to ensure that shipments are not subject to conditions that could compromise product quality, such as exposure to excessive light or high levels of humidity. The system can even detect whether a truck stops unexpectedly or drives over uneven surfaces, which can jostle the shipment, resulting in bubbles that could damage the final product before delivery. According to Stubbs, AstraZeneca (Cambridge, U.K.; www.astrazeneca.com) has employed such advanced tracking capabilities across its global supply chains.

Batteries power efficiency

One area of critical importance in logistics monitoring is the batteries that power a fleet of assets. Batteries must be properly charged and maintained to ensure continued high-performance operations. With this in mind, Ametek Prestolite Power (Troy, Ohio; www.prestolitepower.com) has developed the Insight cloud-based reporting tool that helps to manage battery-powered assets, such as forklifts. "The tool helps to identify maintenance needs and bottlenecks and makes data available remotely," explains Jeff Harrison, business manager for Ametek Prestolite Power. "We have a device that we install on each battery that measures several aspects of the battery's performance," he continues. These measured factors include the battery's temperature and whether the battery has been equalized and watered on schedule. Equalization is an important protocol for battery health and is typically completed once a week. Since most forklifts are powered by lead-acid batteries, proper watering is required to maintain the correct electrolytic levels within the battery. Not only does the system measure those key metrics of battery health, it also provides status data on how the battery is being used, how many hours it is in service and when it is idle and available to be charged. According to Harrison, a key benefit of having all of this information on hand is that it holds operations and maintenance personnel accountable. "Five years ago, this technology was unheard of. Battery health monitoring was still wired and was more time-consuming and costly." As users' analysis of data continues to evolve, Harrison sees great potential for predictive capabilities: "People can see where problems are before they actually kill the battery and impact productivity. We can actually predict when a battery is going to fail."

Automation is another area where the logistics sector is set to experience a fundamental shift. "There has been a huge push in the industry for automatically guided vehicles," says Harrison. The advent of operatorless forklifts certainly brings productivity benefits, but also introduces challenges. "We have to develop a battery charger that is capable of recharging without a person," explains Harrison. Although automated forklifts are currently quite expensive, Harrison expects that users will experience a relatively quick return on investment due to efficiency gains.

Alongside digital monitoring and automation, another trend in forklifts is the use of lithium-ion batteries (LIBs). "Right now, probably less than 1% of all forklifts have LIBs, but I think that's going to expand quickly as the costs come down, because there are so many benefits," says Harrison. Compared to lead-acid batteries, LIBs require less maintenance, can charge faster and have double or triple the service life. However, Harrison mentions that LIB safety and end-of-life recycling options are major concerns.

At Achema 2018 (June 11–15), Stöcklin Logistik AG (Dornach, Switzerland; www.stoecklin.com) is introducing the world's first LIB for forklifts designed for use in explosion-protection areas. The benefits of using LIBs are considerable, but explosion risks have limited their application. The new batteries were approved for use in Zone 1 (2G) gas atmospheres earlier this year, and the company expects to receive certification for use in Zone 21 (2D) dust atmospheres very soon. "Until now, lithium batteries were considered dangerous and unpredictable, and designing a battery for explosive areas was not considered practical because of the high risks," says Jörg Backhaus, ATEX representative at Stöcklin Logistik. In developing their new LIBs, Stöcklin considered many factors to guarantee safe operations up to 300°C. They chose lithium iron phosphate as the cell material and evaluated a combination of cylindrical and prismatic cell structures and cathode and anode materials. Active balancing of the cell and thermal stability were also important factors. "There are standard safety systems, such as a current-interrupt device and a positive-temperature-coefficient function that prevent thermal runaway," says Backhaus. In R&D tests, the company demonstrated that the explosion pressure of the batteries was extremely high — in some cases, 2–3 times the typical expected explosion pressure. The ability to achieve these explosion pressures led them to seek a patent for LIBs for potentially explosive areas.

According to the company, if proper handling procedures are followed, the batteries can be used for as many as 5,000 cycles. This longer service life translates into benefits for forklift drivers, in that fewer battery changes are required, reducing employees' exposure to battery acids. Beyond forklifts, other potential areas of application for explosion-proof LIBs include the mining sector and in cleanrooms, where they eliminate the gas-release risks that go along with lead-acid batteries.

Supply-chain sustainability

Alongside efforts to increase efficiency, providers of supply-chain solutions are also looking for ways to make operations more sustainable. Sometimes, seemingly simple changes can realize substantial benefits. For instance, HOYER Group (Hamburg, Germany; www.hoyer-group.com) began offering tanks constructed of composite materials rather than stainless steel. According to HOYER Group, the first company to employ these composite tanks was BASF SE (Ludwigshafen, Germany; www.basf.com). The tanks are constructed of a lightweight composite material with thermal properties that reduce the heating requirements for tanks. "Due to the lighter weight of these tanks, 2,000 kg more of liquid chemicals can be handled within the defined payload of a transport, thereby reducing travel, costs and CO_2 emissions," says Andreas Essinger, director of sales and business development at HOYER Group's Chemilog unit. Reducing the number of trucks on the road is increasingly important as routes become more crowded and the pool of qualified drivers gets smaller. "Europe's transportation infrastructure is congested. In some of the areas close to European chemical industry sites, traffic jams are increasing, which decreases productivity," explains Essinger.

Ensuring that personnel are properly trained is another aspect of sustainability, especially in situations where hazardous materials are handled and transported. HOYER Group recently announced an expansion of its onsite logistics activities at the Shanghai manufacturing site (Figure 2) of Covestro AG's (Leverkusen, Germany; www.covestro.com) Coatings Adhesives Specialties business unit. According to HOYER Group, while the logistics concerns of chemical manufacturers like Covestro are mostly similar to companies in other sectors, all workers must be rigorously trained to ensure optimal operations for both onsite and offsite logistics activities (Figure 3). "The product needs to be handled safely and carefully, the quality needs to be maintained and the logistics services need to be on time," says Ulrich Grätz, global director of supply chain solutions at HOYER Group. ■

Mary Page Bailey

HOYER Group

FIGURE 3. Logistics workers who encounter chemical products must be sufficiently trained in the proper handling techniques

Simplifying Integration of Modular Projects

Plug-and-produce concepts for automating modular skids may solve integration challenges

Modular construction — both of facilities and process skids — has gained popularity due to its benefits, including speed of delivery and predictability of cost and schedule (see Box 1 below and *Chem. Eng.*, June 2017, pp. 44–50). However, with the process industry embracing big data, Industry 4.0 and the industrial internet of things (IIoT), reliance on automation is also growing, which sometimes is at odds with modularity, as the automation of modular skids can, at times, be difficult to integrate with higher-level, plant-wide control systems. Fortunately, the automation industry is making strides to overcome these difficulties via the development of modular automation systems based on Lego-like and plug-and-produce concepts.

The term "modular" can apply to anything from a simple, pre-assembled process unit to larger skid modules that form entire production lines to multiple container modules joined together to construct an entire facility. Modules can be simple, off-the-shelf units or complex custom-engineered solutions. But in all of these scenarios, if the module is not a stand-alone unit, it must be integrated into the higher-level control system of the plant, and this is where things get tricky.


Jacobs

FIGURE 1. Lubrizol's highly reactive poly-isobutylene production unit from Jacobs' EPC project site in Deer Park, Texas

Impact on automation

Process module automation is commonly accomplished in one of three ways, according to Tim-Peter Henrichs, marketing manager (chemical industry), with Yokogawa Deutschland GmbH (Ratingen, Germany; www.yokogawa-blog.de/en):

THE MANY BENEFITS OF GOING MODULAR

Modular construction, whether it's a simple skid-mounted filtration system, an entire process line containing mixers, reactors, heat exchangers, pumps and the like, or a complete facility, constructed of multiple process modules or containers that are connected together at the user's location, provides a host of benefits and cost savings when done correctly. The modular concept means all the necessary components, both process and ancillary equipment such as piping, instrumentation and electrical wiring, are installed in a structural steel frame or mounted on a skid in a modular shop. Everything is tested before delivery, the module is shipped via truck or barge and, finally, installed on site. While there may be various levels of modularization, all modules are pre-fabricated to the maximum level of completion at a yard that is remotely located from the customer's plant site. Modular yards are often indoors and operate on an assembly-line-type premise, which provides many benefits.

"The objective of modular plants and process skids is to support faster and easier commissioning during startup of a process plant and during changes of production in the lifecycle of a process plant," says Tim-Peter Henrichs, marketing manager (chemical industry) at Yokogawa Deutschland GmbH (Ratingen, Germany; www.yokogawa-blog.de/en). "This is a significant prerequisite for flexible production, which is a big trend in specialty chemicals, pharmaceuticals and life science, as well as in LNG and marine markets."

The biggest benefit, according to Jim Flake, director of module consulting with Jacobs Engineering (Dallas, Texas; www.jacobs.com), is mitigation of labor availability at the sites where large projects are being installed. "Especially in the U.S. and the Gulf Coast area, there is a strain on labor and we continue to see the available skilled craft labor pool erode," he says. "Being able to move work off site and out of the area means you aren't competing for the same labor pool, which is a huge benefit" (Figure 2).

The modular approach also provides schedule and cost certainty, according to Jason Baron, power and controls group manager, with EPIC Process Systems (St. Louis, Mo.; epicsysinc.com). "We are building the system in our shop so contractors aren't on the facility site. Not only can on-site construction be inconvenient, sometimes it's impossible for a plant to operate during large-scale construction," he says (Figure 3). (*continued on p. 19*)

(*continued from p. 18*)

In addition, site prep work, such as preparing foundations and getting ready for the modules to arrive, can be done in tandem with the module's construction, greatly accelerating the project timeline. Also, says Baron, building within a controlled-environment modular yard provides a cost savings when compared to having contractors onsite, where they may be subject to weather and permitting delays, which can increase labor and project costs.

"Also helping to speed up schedule and delivery is the fact that when building the whole system modularly in-house, we can fully test the system before it gets to the site," says Baron. "That reduces time spent with on-site startup and troubleshooting because the system is already tested and ready to go."

Other benefits of going modular include increased safety and quality, says Preston Wendel, global director of fabrication, with Fluor Corp. (Irving, Texas; www.fluor.com). "Usually there are multiple levels to a plant and a lot of critical activities for a project include working at heights, but when we modularize a job, we can take some of that work and bring it down to grade which removes many of the hazards associated with working at heights," he says. "There's also safety improvements due to the repeatability of work performed in the same location using the same standards."

This repeatability also yields quality improvements, says Wendel. "Moving from a stick-built environment, where everything is new, to a manufactured modular approach, where there is repeatability, provides increased quality. We see better rejection rates on welding and overall better quality coming out of modular yards compared to what we see on stick-built jobs" (Figure 4).

Modular construction, especially process skids, can also provide flexibility, says Craig Correia, director of process industries for North America, with Festo (Islandia, N.Y.; www.festo.com).

"Modularity allows processors to be more flexible with production because modules can be moved or placed in series. They can scale up certain sections of the plant if they need to fix a bottleneck or increase production without having to duplicate or redesign," he says. "Ten or fifteen years ago, the plant was designed for a particular purpose and if a change was necessary, you had to interrupt the process to expand equipment that was currently in use. Modules are designed to be used in series and moved around as capacities increase or the product changes." ❑

- The module has no automation system and control is accomplished via the plant's automation system, which is common with simple modules. In this scenario, wiring must be run from the plant's automation system to the module's field devices via hardwiring or a multiplexing system.
- The plant's existing automation system connects to the module's I/O (input/output) via a digital connection, common with more complex modules. This approach allows the module builder to prewire all I/O to field devices, so the plant's automation system only needs to connect to the I/O via a digital data link.
- The module has its own automation controller, which is linked to the plant's automation system via a digital connection, common with more complex modules, allowing the module builder to test module and automation system operation prior to shipment. The module's automation system may not be familiar to plant personnel. Plants can specify the type of automation system, but this may drive up costs and delivery time.

"Often, the mechanical exchange of a process module requires less time than the integration of the module and plant automation systems," says Henrichs. Common problems include difficulties in establishing digital connection, incompatibilities between the plant's automation system and the module's I/O, lack of plant personnel's familiarity with the module's automation system and different naming conventions for tag names, alarms, events and commands. Modular automation allows module vendors to include and protect their intellectual property and also helps their end users by reducing the costs and time required to build and operate flexible production plants.

Integration problems magnify when there are multiple skids manufactured and delivered by different

GUIDING THE WAY TO MODULAR AUTOMATION

The User Association of Automation Technology in the Process Industries, (NAMUR; Leverkusen, Germany; www.namur.net) is an international association of user companies with interests concerning automation technology. With over 140 member companies, the organization conducts dialogue with manufacturers, creates working groups in the areas of measurement, controls, automation, communications, process management and electrical engineering and publishes recommendations.

The Automation of Modular Plants working group is involved in national and international standardization. As such, NAMUR published recommendation NE 148, "Automation Requirements Relating to Modularization of Process Plants."

The recommendation aims to reduce time between idea and product launch via process engineering new designs, using modular components. According to the recommendation, "plug-and-produce" plant components increase flexibility and shorten project duration.

The group states, "During the last decades, a lot of standards for traditionally designed plants were created. Within the process industry, modular plant design and its standardization have just started. The introduction of modular-composed process plants must not be slowed down by insufficient automation technology. Instead, automation is supposed to be a driver and innovator. Furthermore, many of the required developments can become a competitive advantage in traditional installation. NE 148 provides a respective frame for automation in modular designed plants."

The main concepts included in NE 148 are decentralized automation, with individual modules being fully automated, as well as flexible integration into higher-level, plant-wide control systems and vendor-independent integration of modules. ❑

vendors, explains Gordon Bordelon, chemical industry lead, with Rockwell Automation (Milwaukee, Wis.; www.rockwellautomation.com). "One of the biggest issues is that it creates project risk," he says. "When implementing a project, there are often different systems with different automation technologies, so you have to make sure upfront that they are going to be consistent. If you get to the startup and commissioning stage and then realize that one system can't communicate with another or that the skid can't be integrated, the costs are much higher as the remediation occurs on site, delaying startup and ultimately missing production schedules."

Operational readiness can also be negatively impacted. "Whether you have one module or an entire modular facility, it is a problem if the automation is inconsistent," says Bordelon. "The operations staff at the facility must know how to operate all the systems, which is problematic if the automation is inconsistent." In addition, the modules usually need to be tied into business systems such as laboratory information-management systems (LIMS), enterprise resource-planning systems (ERP) and computerized maintenance-management systems (CMMS). "These modular plants not only have to be able to operate, but they also require the ability to share data and communicate with other business systems in order to be operational-ready," notes Bordelon.

And, information sharing is more important than ever in the current data-centric environment, says Greg Turner, global OEM process segment business leader, with Rockwell Automation. "Not only are we changing how we build plants, but at the same time, we are increasingly relying on automation to accommodate Industry 4.0 principles, big data and the industrial internet of things, so plants and processes are becoming more complex and interconnected." Proper integration of the automation system permits situational awareness for the people running the plant and allows them to use data to plan predictive maintenance, examine alarm conditions and understand the health and efficiency of the equipment and processes. "This type of situational awareness falls under asset utilization and can be adversely affected if automation is inconsistent in a

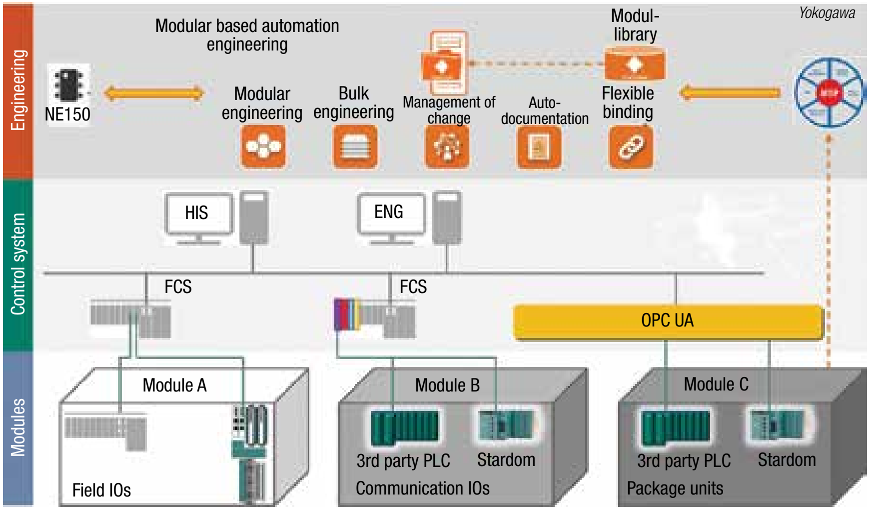


FIGURE 2. Chemical and pharmaceutical-related industrial associations are discussing a technology concept, called a Modular Type Package (MTP), to support easy integration of any type of controller. MTPs are based on Automation Markup Language (AML) technology in which the significant information of the process module automation application can be exported for easy integration with any upper automation system

modular environment," says Turner.

Safety can be another issue in modular plants. "In the environment of the chemical industry, safety is very important. There are emergency shutdown systems and safety instrumented systems (SIS) and modules have to be consistent with those systems," notes Craig Correia, director of process industries for North America with Festo (Islandia, N.Y.; www.festo.com). "If there is an emergency shutdown, the module can't go rogue. It must cooperate with the safety system. You can't have a module with a safety protocol or shutdown system that isn't consistent with the equipment in other areas. In addition, it's important that the interfaces look the same from skid to skid. In layman's terms: you can't have one emergency stop that's a round, red button that you physically push and another that's on a touchscreen because this could confuse operators. Consistency in safety is crucial."

A modern module approach

While a remedy is necessary, integration of modular components is still a work in progress. However, component providers, module builders and automation suppliers are all working toward the common goal of simplifying integration between module automation and higher-level control systems.

On the component level, manufacturers like Festo are embedding controllers on instruments and devices so they can be tested when used in a modular process skid and are making sure that the control is neutral so their controller can "handshake on the supervisory level with the 'big boys' in the marketplace," says Correia. "It is our responsibility that our controller can pass all the relevant information and handle all the safety protocols being exchanged between the skid and the automation system. We are continually evolving and getting better at this."

On the module side, builders are simplifying the physical connection, says Ted Faiella, senior director of Honeywell UOP's (Des Plaines, Ill.; www.uop.com) Applied Process Excellence Center. Traditionally, modular units were automated by installing junction boxes within the modules. "All the instrumentation on the module was connected to junction boxes at the module-fabrication shop so continuity checks could occur before shipment. At the plant, this junction box connected to a marshalling rack, which connected to the actual I/O cards," Faiella explains. "But, within the last five years, this has changed. We now provide universal process-control cabinets (UPCs) that contain I/O cards. This eliminates the traditional wiring method," he says. "Instead, the I/O cards are in the field and you only need to run fiber optic cabling from the UPC box to the control room."

EPIC Process Systems

FIGURE 3. The modular approach provides schedule and cost certainty because module systems are built in a shop so contractors aren't on the facility site

"This simplifies field wiring and the associated check out and reduces the size of the control room, while also reducing costs and allowing fewer things to go wrong," adds Amy Gavin, senior marketing product line manager for modular with Honeywell UOP.

Meanwhile, automation suppliers are making progress in the areas of open architecture and modular automation concepts. "Chemical and pharmaceutical-related industrial associations are discussing a technology concept to support easy integration of any type of controller," says Yokogawa's Henrichs. "This is called a Module Type Package (MTP) and is based on Automation Markup Language (AML) technology in which the significant information of the process module automation application can be exported for easy integration with any upper automation system" (Figure 2).

Currently, says Henrichs, modular-type automation packages do exist. "They cover the HMI (human machine interface) and communications use cases," he says. "The orchestration and other needed functions are on the way and will complete the full MTP concept step-by-step."

David Funderburg, global technology manager, product group, chemicals and refining, and industrial automation for oil, gas and chemicals, with ABB, Inc. (Cleveland, Ohio; www.abb.com), agrees that MTPs are the current working solution to the problem. "They provide a standard way to integrate skids," he explains. "The skids come configured and part of the delivery includes a standardized XML packet, or a modular type package, that integrates into the HMI system and automation platform, so we don't have to worry about rebuilding displays for consistency. Even if you have 20 skids from 20 different vendors, as long as they all have this module type package, the communication and HMI will look and act the same. Even if I take the same MTP and import it into a competitor's HMI package, it will still look the same and the layout will still be the same and the performance will be the same. This allows reduced engineering costs because integration is simplified."

Rockwell Automation is focused on creating customizable off-the-shelf packages that have "pre-tested fundamental building blocks," known as Process Object Libraries, which vendors would use to develop their skid control systems. "By using these building blocks with the vendor's IP to design the controls, it provides consistency," says Rockwell's Bordelon. "If a processor used multiple skid vendors and our application libraries, the complexity of applications, complexity of maintaining the systems and the data flows and constructs would be consistent enough to cut down on integration issues. It all fits together because of the standardization of these library objects and the way they hang together."

"These open approaches and standardized applications mean we, as automation suppliers, are moving down the path to provide business advantages to the end users," says Rockwell's Turner. "They want and need to shorten startup time and reduce integration costs associated with putting different skids together. They are looking not only to get consistency within the plant, but also from plant to plant so they can move skids from place to place throughout their organization without creating an integration nightmare." ■

Joy LePree

Fluor

FIGURE 4. Fluor used modular execution while building Dow's ethylene production facility in Freeport, Texas

Focus on Sensors

Endress+Hauser

Sensor Technology

Baumer

SOR Controls Group

Hygienic optical sensor measures dissolved oxygen

The Memosens COS81D hygienic optical sensor (photo) measures dissolved oxygen in fermenters and bioreactors that are used in the food, pharmaceutical and biotechnology industries, and in drinking water and boiler-feedwater applications, as well. It can be used in all measuring points, from laboratory fermenters to production processes. This device measures dissolved oxygen, gaseous oxygen and temperature, with an accuracy to ±0.2%, says the company. It works in process temperatures from 15 to 280°F, and pressures from 0 to 190 psi. The compact stainless-steel sensor meets EHEDG (Type EL Class 1) and ASME BPE (including USP Class VI and FDA conformity) hygienic requirements to avoid product contamination. It also meets the requirements of GMP and GLP, and is designed to withstand clean-in-place and steam-in-place procedures, according to the manufacturer. — *Endress+Hauser, Greenwood Ind.*

www.us.endress.com

Optical transducers provide dynamic torque measurement

The digital ORT 230/240 Series optical rotary torque sensors (photo) provide precise, dynamic measurement of rotary and static torque of less than 100 Nm, for bandwidths of up to 50 kHz. These new devices replace the company's E200 ORT Series, and feature advanced electronics that deliver improvements in resolution, frequency response, reduced current consumption and faster digital data throughput, says the manufacturer. Non-contact operation is said to ensure a long, reliable life with high accuracy and noise immunity, and the company offers a lifetime warranty. These sensors include self-diagnostics that report when the transducer's torque, speed ratings or calibration data have been exceeded. Additional sensors monitor shaft temperature for improved compensation and accuracy. Integral software enables data display and recording. — *Sensor Technology Ltd. Banbury, U.K.*

sensors.co.uk

Piezoresistive pressure sensor has a tiny footprint

The Micropressure MPR Series pressure sensor is a small, piezorestive silicon device. The sensor has a package footrpint of just 5-by-5 mm (0.20-by-0.20 in.), and it measures pressure from 0.6 to 30 psi, over a compensated temperature range of 32–122°F. It is fully calibrated and compensated to provide digital output, and is easy to implement into a range of end products. The device is compatible with a variety of liquid media, making it suitable for applications such as liquid-level measurement, and is available with a food-grade or medical-grade gel for applications requiring food-grade or drinking-water certification. — *Honeywell, Fort Mill, S.C.*

www.sensing.honeywell.com

Laser sensors precisely detect very small objects and gaps

The miniature 0300 Laser Sensors (photo) provide pinpoint accuracy for the detection of objects to within 0.1 mm, with response times of less than 0.1 ms. The five sensors in this product family precisely detect very small gaps and objects, even when closely spaced, so they are ideally suited for fast or high-throughput processes, such as assembly and handling, packaging, pharmaceutical and food-and-beverage applications, says the company. Thanks to a laser beam that focuses to within 0.1 mm, objects can be positioned with high precision and controlled precisely. The company's accompanying qTarget process for alignment, and qTeach training procedures, ensure fast, reliable commissioning of the sensor, says the manufacturer. — *Baumer Ltd., Swindon, U.K.*

www.baumer.com

This device samples low-vapor-pressure liquids

The RSS RAM Sample System (photo) is the latest addition to this compa-

Note: For more information, circle the 3-digit number on p. 102, or use the website designation.

ny's Low Vapor Pressure Liquid Grab Sample Systems. The Ram Sample Valve is used to collect representative samples of low-vapor-pressure liquids without exposing the operator collecting the sample, or allowing emissions to escape to the environment, says the company. It is available in a variety of materials and connections, and can be ordered with an extended plunger or piston or extended body to ensure zero dead volume. The system uses a ram- or piston-type sampling valve, which is said to be ideal for collecting high-viscosity and hot samples directly from the main line or side of a vessel. — *SOR Controls Group Ltd., Lenexa, Kan.*
www.sorinc.com

Inductive proximity sensors withstand harsh environments

The Bulletin 871FM miniature metal, flat-pack, inductive proximity sensors (photo) are enabled with IO-Link technology. This allows the sensors to deliver more comprehensive diagnostic and parameter data to controllers over Ethernet/IP from the IO-Link master module — an advanced capability that is said to help minimize downtime and increase productivity. When connected to an Allen-Bradley 1732 Point I/O or 1734 ArmorBlock I/O-Link master, the sensor delivers data into the control system to optimize machine setup, maintenance and troubleshooting. Unlike traditional, tubular proximity sensors, the fully shielded Bulletin 871FM sensors have 8- and 14-mm stainless-steel rectangular housings, which can be installed in low-profile, space-critical applications.Their compact design and all-stainless-steel construction makes them ideal for sensing small parts in demanding environments, says the manufacturer. — *Rockwell Automation, Milwaukee, Wis.*
www.rockwellautomation.com

A full slate of positioning sensors, for immediate delivery

This company provides a broad array of standard and custom, a.c.- and

Rockwell Automation

NewTek Sensor Solutions

BinMaster

GF Piping Systems

d.c.-operated linear position sensors and signal conditioners (photo, p 25) with short delivery times. They are designed for a diverse array of applications, ranging from power generation, oil-and-gas exploration, chemical processing, factory automation, dimensional gaging and more. Standard, miniature, hermetically sealed, high-pressure and high-temperature designs are available. All products are manufactured in the U.S., and many are in stock, allowing for next-day delivery. — *NewTek Sensor Solutions, Pennsauken, N.J.*
www.newteksensors.com

Teflon-coated level sensor is undaunted by sticky powders

The Teflon-coated sphere used in the SmartBob level sensor (photo) is designed for applications handling sticky powders and other bulk solids, or those that are prone to static cling (such as silica, fracking sand, minerals, powdered chemicals, additives and ingredients). By resisting product buildup on the sensor probe, this device helps to reduce maintenance needs while ensuring accurate, reliable level sensing in bins, tanks and silos. The sensor probe is automatically dropped to the material surface. When it makes contact with the surface, it immediately retracts, calculating the measurement from the top of the silo to the material surface. The device is compatible with the company's Binventory software, BinView remote-data monitoring web application and C-100 display console, to help operators manage the data. — *BinMaster, Lincoln, Neb.*
www.binmaster.com

Smart sensor electronics improve pH/ORP monitoring

The Signet 2751 DryLoc pH/ORP (oxidation-reduction potential) Smart Sensor Electronics (photo) provide pH/ORP monitoring and control by alerting users to probe health, including needed maintenance, glass impedance or probe failure (via, for instance, broken-glass detection). The device is suitable for use in water and wastewater treatment, scrubber control, effluent monitoring, flocculent coagulation, surface finishing and other applications. The 2751 features two different outputs — a two-wire 4–20-mA loop output with optional EasyCal functionality, or a digital (S^3L) output, which allows for longer cable lengths and is compatible with the Signet 9900 Transmitter (Gen IV), 9950 Dual Channel Transmitter or Signet 0486 Profibus Concentrator, the 2751 virtually eliminates inaccurate pH/ORP readings by automatically monitoring electrode condition and generating an alert to potential problems before they become more serious. The Smart-Sensor Electronics allow for easy calibration of electrodes in a laboratory setting, as well as installation of pre-calibrated probes in the field, thereby reducing system downtime, says the company. Memory-chip-enabled electrodes will store operational data, such as minimum and maximum pH/mV readings, runtime, minimum and maximum temperature, for troubleshooting and operational evaluation. The device provides pH measurement from –1 to 15, and ORP measurements from –1,999 to 1,900 mV. The 2751 is available in three package styles (one submersible and two inline versions). — *GF Piping Systems, Irvine, Calif.*
www.georgfischer.com

Fiber-optic kinetic sensors meet challenging needs

This company offers a wide array of fiber-optic kinetic sensors for industrial and medical operations. Products include fiber-optic position sensors, rotary and linear encoders, signaling devices, microswitches, accelerometers and temperature sensors. These sensors are designed for challenging applications, where immunity to EMI, RFI, microwaves, high voltage, magnetic fields, radiation or explosive atmospheres is required, as well as MRI compatibility or long-distance operation is needed, says the company. It recently received ISO 9001L2015 certification from TüV Nord USA. — *Micronor, Inc., Camarillo, Calif.*
www.micronor.com

CO_2 sensor supports food-preservation efforts

Modified Atmosphere Packaging (MAP) is used to prolong the shelf life of fruits, vegetable and salads with a specific level of CO_2 to keep produce fresher longer The optimal level of CO_2 needed to extend the shelf life of produce varies by the product being pre-

Gill Sensors & Controls

Dwyer Instruments

Sensorex

served. Typically, during inert-packaging efforts, sample packages are tested at regular intervals and the CO_2 levels checked by inserting a hollow needle to draw out a sample of packaging gas for analysis. The longer the read time for CO_2 analysis, the more packages are able to move through the line before detection indicates the wrong CO_2 level. The Storage Control Systems Portable Gas Sensor allows CO_2 analyses to be carried out in seconds, using only a small sample volume. The portable device uses a SprintIR InfraRed CO_2 sensor from this company. — *Gas Sensing Solutions (GSS), Cumbernauld, U.K.*
www.gassensing.co.uk

Magnetic cylinder sensor is ideal for robotics applications

The MZCG magnetic cylinder sensor is designed for position detection in pneumatic grippers or miniature pneumatic cylinders that have C-slots. With a universal housing design, the MZCG fits into a wide range of C-slots from the most common manufacturers, which reduces storage costs and allows for a more flexible machine design, says the manufacturer. With an extremely short housing (just 12.2 mm) and a 90-deg rotated radial cable connection, this sensor is designed for small drives. Its patented design makes mounting quick and easy, says the company. — *Sick AG, Waldrich, Germany*
www.sick.com

Liquid level sensor is undaunted by sticky fluids

Monitoring levels of sticky or viscous materials is always challenging, as these fluids can lead to clogged float mechanisms, blocked fill ports, solid buildup on moving floats and masked windows. The new Model 7014 high-viscosity liquid-level sensor (photo) has a proprietary conductive technology that is designed for monitoring highly viscous (water-based) liquids. It has an electrically sensitive probe surface and no moving parts or floats, so there is nothing to clog, wear or freeze, allowing for a reliable signal reading while reducing maintenance needs, according to the manufacturer. The probe also features wetted parts manufactured with fluorinated ethylene propylene (FEP). The smooth sensing surface can differentiate between being immersed in thick liquids versus the airspace at the top of the tank or container, enabling more accurate calculation of true liquid level. — *Gill Sensors & Controls Ltd., Los Angeles, Calif.*
www.gillsc.com

Rugged device monitors carbon dioxide levels

The Series CDWP Carbon Dioxide Transmitter (photo) can be utilized to monitor the CO_2 concentration in applications such as HVAC and CO_2 refrigeration mechanical rooms or greenhouse gas applications. It uses a single-beam, dual-wavelength NDIR sensor, which eliminates light source aging effects. The Series CDWP is available in multiple range limits and comes standard with universal outputs of 4–20-mA and 0 to 5 or 10 V d.c., for use with most programmable logic controllers or building-management systems. The device uses a IP54-rated housing, which protects the electronics from dust and splashed water, while the powder-painted, die-cast aluminum housing is said to be an improved material over polycarbonate housings. Its electrical connection allows the user to quickly disconnect the unit from the power and controller, resulting in faster and easier cleaning. — *Dwyer Instruments, Inc., Michigan City, Ind.*
www.dwyer-inst.com

Small-footprint sensing system meets lab needs

The SensoLab benchtop meters and configurable kits (photo) offers researchers a more complete sensing system to carry out pH/ORP/conductivity monitoring. The PM1000 pH/ORP meter and CM1000 total dissolved solids (TDS) meters pair with the company's broader offering of laboratory sensors, which include basic, advanced and research-grade options to maximize measurement accuracy and sensor lifetime in a range of chemical process, pharmaceutical, biomedical and other applications. An intuitive interface guides users through setup, calibration and measurement, with easy-to-read prompts and results displayed on its integrated screen. — *Sensorex, Garden Grove, Calif.*
www.sensorex.com ■

Suzanne Shelley

KEM Küppers Elektromechanik

Siemens

Enexio Water Technologies

Ross Systems and Controls

The first H_2 flowmeter certified for dispensing applications

The TCMH 0450 High Pressure TRICOR Coriolis flowmeter (photo) is said to be the world's first MI-002 / OIML137-certified Coriolis flowmeter for hydrogen dispensing applications. By securing this certification, the TCMH 0450 can now be used in custody-transfer applications — specifically in H_2 dispensing stations for the fast-growing H_2-powered vehicle market. By using the TCMH 0450 flowmeter, companies can sell H_2 fuel to end users with taxation. Without a certified fuel dispenser, the taxation of H_2 is not possible. Because H_2 is so light, flowmeters in hydrogen dispensers must operate at high pressures (up to 1,050 bars), and tolerate extreme and rapid temperature changes. — *KEM Küppers Elektromechanik GmbH, Karlsfeld, Germany*
www.kem-kueppers.com

Dual sensor operation with four-wire sensor connection

The Sitrans TH320/420 and TR320/420 HART temperature transmitters (photo) cover a wide range of sensor types suitable for mounting in sensor-head and rail mounting. They feature high availability of the measurement signal and ease of use. Due to the safety integrity level (SIL) 2/3 certification according to IEC 61508, these temperature transmitters are particularly suited for safety-critical applications. The devices also have a large number of country-specific explosion protection certificates for all zones. They provide reliable results, even under extreme conditions down to –50°C. Main application areas include industries such as chemical, oil and gas, marine and power generation. — *Siemens AG, Nuremberg, Germany*
www.siemens.com

Free-standing separators that are modular and flexible

The new SKT separator models (photo) are square, made of plastic, glass-reinforced polymer, steel or stainless steel and can be optionally delivered with one or more flocculation tanks, agitators and rabble rakes and all necessary peripherals. Expansion by new modules is possible at any time. The modular design allows flexible responses to changes in process requirements. In comparison to conventional sedimentation tanks, the free-standing separators require a much smaller installation space — space savings of up to 90% are possible. Further savings result from lighter, smaller foundations and lower transport, installation and maintenance costs. Since sludge draining is done by hydrostatic pressure, usually no pumps are required, which helps save energy costs, says the company. Inside the tank, a TUBEdek parallel-plate pack ensures a reliable separation process. The great number of equidistant sedimentation levels of the chevron-shaped channels provides the system with a high hydraulic capacity and supports sludge removal. — *Enexio Water Technologies GmbH, Herne, Germany*
www.enexio.com

Mixer panels with additional UL and NFPA certifications

This company recently completed the qualification to self-certify its touch-screen purged panels (photo) as meeting the standards of Underwriters Laboratories' UL-698A Code and the National Fire Protection Association's NFPA-496 Code. UL-698A covers industrial control panels designed for hazardous locations, including the use of intrinsically safe barriers. NFPA-496 standards relate to purged and pressurized enclosures. Purge systems are an alternative to traditional NEMA 7, 9 explosion-proof enclosures and are suitable for most all hazardous locations, including: Class I, Div. I & II for gas and vapor environments; and Class II, Div. I & II for dust environments. Purge panel enclosures can be NEMA 4 carbon steel or NEMA 4x stainless steel, depending upon the requirements. The ability to self-certify enables this company to offer UL and NFPA labels on explosion-proof panels at a lower price, without the additional cost for a third-party inspection. The new certifications are in addition to UL-508A (non-hazardous control panels), which the company has maintained for more than a decade. — *Ross Systems and Controls (SysCon), Savannah, Ga.*
www.mixers.com

Lights with reduced blue content for special applications

For certain fields of application in the pharmaceutical industry and in photograph development, where a high blue content in light might compromise the quality of the products, this company offers durable, maintenance-free alternatives in the product portfolio; for example, the light-emitting diode (LED) tubular light fittings Series 6036 (photo). Through targeted conversion of the emission spectrum of the LEDs, Light fitting variants with a very low color temperature of about 1,700K are available. With such a minimized blue content, they achieve twice as much efficiency as filtered fluorescent lamps. The light, which is shifted spectrally into the yellow, preserves a certain color rendering, so that color differences and contrasts remain clearly visible. These energy-efficient light fitting variants are also suitable for replacing conventional sodium-vapor lamps and remain reliably operational even in extreme temperature conditions ranging from –55 up to 60°C. The Series 6036 is available with IP66/68 protection, and lengths of 75, 110 and 140 cm, with a service life of up to 100,000 h. — *R. Stahl, Waldenburg, Germany*

www.r-stahl.com

R. Stahl

The launch of an online configurator for composite hoses

Users of the Configurator (photo) are able to create and compare millions of possible hose combinations, providing purchasers with a time-saving platform without needing to look through numerous datasheets and brochures. It is a fast and safe service to visualize a required hose assembly or place an order. The composite-hose manufacturer supplies 66 different hose types available in sizes from 1 to 10 in., and the Configurator helps the user to easily pick the required hose type by filtering selected specifications. These factors include; application group, material liner, inner helix, outer helix, maximum working pressure, fire-safe

Dantec

technology and the maximum and minimum temperatures. Once the user has selected the hose type, they are able to virtually build the composite-hose assembly by selecting the required size, length and required end couplings and securing method in five simple steps. — *Dantec Ltd., Moreton, Wirral, England*
www.dantec.com

Electrical thermometers for very cold conditions

This company now also offers electrical thermometers in a version for ambient temperatures down to –60°C (photo). This version has been tailored for applications in the crude oil, natural gas and petrochemical industries operating in polar climates. The thermometers for extreme cold are said to be as accurate as standard instruments for ambient temperatures down to –40°C, but these devices are made of application-specific and appropriately cold-resistant components. Each ready-to-use thermometer and its components are tested in line with the requirements at a test temperature of –70°C, for thermal shock resistance in accordance with IEC 60079-0 and for an IP protection in accordance with IEC 60529. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*
www.wika.de


WIKA Alexander Wiegand

Ethernet patch panels for fast connection and safe supply

Ethernet patch panels enable a quick and easy connection between the field and control cabinet cabling. The eight new DIN rail devices (photo) provide various connection options. In the covered wiring space, the connection technologies IDC, Push-in and screw connection simplify the installation of the field cable. The cable shielding is connected without tools, with strain relief assured at the same time. This saves time during installation. The optional surge protection protects the connected end devices, therefore increasing system availability. The additional shield-current-monitoring system enables valuable diagnostics. Any shield currents present, caused by different potentials or EMC, are indicated via an LED. Thus, problems in the installation are indicated immediately, without the need for extensive measurements, says the company. The range is complemented with twelve Power over Ethernet (PoE) injectors, which can supply remote Ethernet devices, such as cameras, with data and electricity via a shared cable. The installation technology and protective functions of the patch panel are being used for the first time in these twelve devices. Along with these new technologies, the devices are available


Phoenix Contact

with up to 60 W power and an electrically isolated power-supply unit. — *Phoenix Contact GmbH & Co. KG, Blomberg, Germany*
www.phoenixcontact.com

A new addition to this line of submersible sump pumps

BJM Pumps

This company has expanded its JX Series line of submersible pumps, to include the new JX150CSS and JX-220CSS (photo). The newest models are designed for applications where caustic or acidic fluids are present, such as those in food, chemical or pharmaceutical processing. All metal parts exposed to pumped liquids are constructed of 316 stainless steel. Other features include: double mechanical seal design, with separate lip seal to protect the motor, and all elastomers, including mechanical seals, are fluoroelastomers (FKM). The JX150CSS has a power of 20 hp with capacity up to 730 gal/min and a 151-ft head, and the JX220CSS has a power of 30 hp handling up to 760 gal/min and 186-ft head. — *BJM Pumps, Old Saybrook, Conn.*
www.bjmpumps.com

A flowmeter for sensitive production processes

To complement automated production plants, for example, in the food, pharmaceutical and biotechnology industries, this company has developed the CMAG magnetic inductive flowmeter (photo). This easy-to-install version of the proven IZMAG flowmeter delivers highly accurate and reliable measurement data, helping users improve dosing and recipe control, minimize risks and optimize resource utilization. Its hygienic stainless-steel design and the aseptic flange make it suitable for sensitive processes in the production and processing of beverages, liquid foods and milk, but also for liquid pharmaceutical, chemical and agrochemical products, personal care products, process waste and sea water, concentrated salt solutions and aqueous urea solutions. The small footprint enables more flexible positioning within the plant. Installation and commissioning do not involve a significant expenditure of time and money, says the manufacturer. — *GEA Group AG, Düsseldorf, Germany*
www.gea.com


GEA Group

A server for I/O expansion and data acquisition

Sealevel Systems

The Relio R1 Seal/O Server (photo) is the latest member of this company's Relio family of industrial computers. Originally developed as a point-of-sale ticketing solution, the R1 Seal/O Server is suitable for harsh industrial environments. With a solid-state, zero-maintenance, compact footprint, this I/O server can be used for mobile, embedded control, test and measurement and I/O-intensive applications. Users can expand the I/O capabilities by adding Seal/O data-acquisition modules. Host connectivity options include wireless, Ethernet, USB, RS-485 and RS-232 to meet a specific application. Each host Seal/O module can support an additional 246 expansion modules for exponential I/O possibilities. Serial ports can be easily added using Seal/O and SeaLINK USB serial adapters. Together the Relio R1 Seal/O Server and Seal/O modules create an incredibly

Enmet

KSB

Eriez Manufacturing

robust remote I/O control and monitoring network. — *Sealevel Systems, Inc., Liberty, S.C.*
www.sealevel.com

Monitor traces of benzene with this GC unit

The eGC environmental gas-chromatograph monitor (photo) is said to be a cost-effective approach to trace-level benzene detection (below parts per billion). The manufacturer has added a new feature — a weather station — that is capable of measuring wind direction, wind speed and offers a GPS feature. It can be configured to operate using solar power, allowing convenient deployment in remote areas. All analysis data are communicated via a cellular modem to the cloud where data can be easily accessed and shared. eGC has been tested to operate outdoors under harsh real-world ambient conditions (–10 to 45°C) and is capable of the accuracy and precision of an analytical laboratory instrument. The eGC is a next-generation fenceline benzene-monitoring system that can be used by petroleum refineries for compliance reporting and root-cause emissions analysis for corrective action. — *Enmet, LLC, Ann Arbor, Mich.*
www.enmet.com

Self-cleaning inserts for wastewater tanks

The ready-to-install, self-cleaning Amaclean tank insert (photo) decreases the amount of stagnant water in the pump sump and reduces the need for maintenance and cleaning. In combination with select impeller types used in the wastewater pumps, this tank insert eliminates the need for flushing valves. Amaclean's patented design and gel-coated inner surface prevent waste and fibers contained in the wastewater from depositing in and at the lower parts of the structure. The tank itself is made of glass-fiber-reinforced polyester, which has a good chemical resistance. Steel reinforcement enhances anchoring in the concrete and transfers the weight-induced forces of the pumps, supported by the flanged bends, into the surrounding concrete jacket of the wastewater tank. All wetted parts are made of plastic-coated cast iron or corrosion-resistant stainless steel. Amaclean is available in three sizes for wastewater sumps with an inside diameter of 1,200, 1,500 or 2,000 mm. — *KSB SE & Co. KGaA, Frankenthal, Germany*
www.ksb.com

UV chromatography monitoring for large-scale purification

The new UV (ultraviolet) Monitor Kit can be easily added to this company's Flash 150 and Flash 400 chromatography systems in pharmaceutical development or manufacturing environments. The new UV Monitor Kit utilizes the latest in fiber-optic connections and powerful software for post-run analysis to give absolute control and confidence in large-scale purification processes. The kit combines a robust UV monitor core with a special wireless tablet, optimized for use in sensitive environments, to provide the most effective PAT (process analytical testing) solution available for the Flash 150 and 400 systems. This combination supports ATEX-compliant installation in the user's production facility or laboratory environment. The system indicates the UV activity of the chromatographic flow eluting from the column, simplifying the workflow while helping to reduce solvent consumption, batch processing time and energy costs through less evaporation. — *Biotage, Uppsala, Sweden*
www.biotage.com

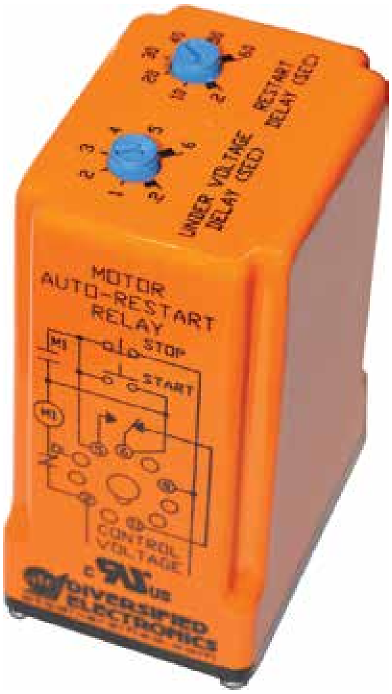
Removing fine iron contaminants with magnetic filters

The Dry Vibrating Magnetic Filter (DVMF; photo) is specifically designed to remove very fine iron-bearing contaminants from hard-to-flow fine powders, such as lithium, which makes it well-suited for both lithium producers and users. The standard design of a DVMF consists of a solenoid electromagnet that generates a magnetic field into the bore of the separation zone. A filter element of expanded metal placed in the separation zone concentrates the magnetic flux of the magnetic field. This produces scores of high-gradient collection zones that capture magnetic contaminants as feed material filters through the element. — *Eriez Manufacturing Co., Erie, Pa.*
www.eriez.com

Gerald Ondrey

Web Only

ATC Diversified Electronics



HMS Industrial Networks

This relay ends costly restarts following undervoltage trips

The new MAR Series Motor Auto-Restart Relay (photo) provides automatic restart to a motor by bypassing the start switch to re-energize the M1 starter coil following a momentary drop or interruption of the control voltage. The MAR Series is suitable for production processes with critical components not in a hazardous area and without permissive circuits. By reducing the need for manual restarts of critical operations throughout a process facility, the devices can easily save users hundreds of thousands of dollars annually in lost productivity, says the company. The MAR Series offers different output interval restart ranges, restart delay ranges, an option for O/L relay L2 disconnect feature, and the choice of 8- or 11-pin plug-in versions. Restarts can be staggered so not all motors come back online all at once, minimizing burden on power capacity. All models are specifically designed to address an undervoltage or power interruption period no greater than 4, 6, or 10 seconds long. — *ATC Diversified Electronics, Newell, W.Va.*
www.atcdiversified.com

Connect devices wirelessly with these new WLAN access points

This company introduced two new Anybus WLAN Access Points (photo) — industrial-grade infrastructure hubs for long-range, wireless local-area network (WLAN) connectivity. The units are suitable for collecting data wirelessly from any machinery or system, especially those equipped with Anybus Wireless Bolt or Bridge. The Anybus WLAN Access Points allow users to set up an industrial wireless infrastructure for multiple wireless clients. Available in two different versions, one for IP30 applications and one for IP67 (outdoor and water resistant), both products feature the same characteristics in terms of range and functionality. The Access Points enable wireless connectivity to all types of industrial equipment, but are especially suited to connect to machinery and systems that are communicating wirelessly via the company's Anybus Wireless Bolt and Bridge. The WLAN Access Points fit seamlessly into any automation architecture, enabling high-performance wireless connections to a multitude of wireless clients. By supporting up to 1,000 Mbit/s wired Ethernet LAN connection and up to 300 Mbit/s wireless connections, high data throughput is ensured for each client. — *HMS Industrial Networks, Halmstad, Sweden*
www.anybus.com

Seal material properties

Department Editor: Scott Jenkins

Fluid seals for chemical process equipment are commonly made from a host of elastomeric and plastic materials. Selecting a seal material requires careful consideration of several criteria. Presented here are short descriptions of the major criteria for seal selection and a table outlining the properties of several of the most common seal materials.

Seal selection criteria

There are many possible factors that may play a role in which seal materials would perform best in a given application, but here are four major ones.

Temperature capabilities. Each seal has a range of temperatures within which it is designed to be used. Near the service limit for each seal, the performance becomes less certain. At low temperatures, elastomers become harder and less pliable. Also, elastomer seals lose their rubber-like properties with decreasing temperatures. The changes experienced by elastomer seals at low temperatures are physical changes, and are generally reversible.

Fluid compatibility. Seals must be chemically compatible with the fluids they will encounter in the process. Significant swelling and rapid deterioration can occur if not. In addition, factors such as concentration, operating pressure and temperatures, seal geometry and design, must be taken into account. Chemical-resistance guides, which are offered by most seal manufacturers, can be good resources.

Resistance to abrasion and tearing. Depending on the requirements, seals may be required to resist scraping and tearing, as well as avoid small nicks and cuts, which can lead to seal failure. Compounding elastomers with internal lubricants can enhance abrasion resistance.

Ability to accommodate differential pressure. Many seals will experience pressure differentials between the process interior and the external environment, so they should resist extrusion. Harder materials are generally more resistant to differential pressure.

TABLE 1. POPULAR SEAL MATERIALS AND APPLICATIONS

Seal material class	Description	Properties
Acrylonitrile butadiene rubber (Nitrile rubber; NBR; Buna-N)	Copolymer of 2-propene nitrile and butadiene	Good abrasion resistance Grades with high acrylonitrile content have higher resistance to petroleum-based fluids Not for use with polar solvents
Hydrogenated nitrile butadiene rubber (HNBR)	Copolymer of acrylonitrile and butadiene, similar to NBR but with subsequent dehydrogenation of the carbon-carbon double bond of butadiene in polymer backbone	Hydrogenation eliminates routes of degradation that can occur in conventional nitrile rubbers HNBR outperforms conventional nitrile rubber with respect to thermal resistance and the ability to handle sour crude oil and other materials
Ethylene propylene diene monomer (EPDM)	Copolymer of ethylene and propylene, with a small amount of a diene monomer to facilitate cross-linking	Compatible with polar fluids Not for use with petroleum-based fluids Good thermal resistance
Fluoroelastomers (FKM)	A class of copolymers consisting of vinylidene fluoride, hexafluoropropylene and other monomers	Suitable for high temperatures (up to 250°C), high pressures and harsh chemical conditions More costly than EPDM and nitrile rubbers Not recommended for ketones and amines
Perfluoroelastomers (FFKM)	Similar to FKM, but higher fluorine content	Higher fluorine content improves temperature resistance (up to 325°C) compared to FKM Broadest chemical resistance of any rubber class
Silicone rubbers	Variations of polysiloxane, an inorganic rubber with a silicon-oxygen backbone and methyl groups or other groups attached to Si atoms	Good temperature resistance Good resistance to ozone, ultraviolet radiation and weathering Poor abrasion resistance Not for use with petroleum-based fluids and ketones Good low-temperature flexibility
Fluorosilicone rubbers	Similar to silicone rubbers, but the functional groups attached to Si include trifluoropropyl groups	Good low-temperature flexibility High-temperature stability Cost is higher than conventional silicone rubbers
Chloroprene rubber (tradename: Neoprene)	Polymer of 2-chlorobutadiene	Good balance of chemical and physical properties at a relatively lower price Not for use with aromatic and oxygenated solvents
TFE/P (tradename: Aflas)	Co-polymer of tetrafluoroethylene and propylene	Excellent chemical resistance to a range of aggressive chemicals Not recommended for aromatic fuels and ketones
Polytetrafluoroethylene (PTFE) (tradename: Teflon)	Synthetic polymer of tetrafluoroethylene	Large temperature range in sealing applications Low coefficient of friction for dynamic seals Broad chemical resistance
Polyurethane rubber	Elastomeric urethane rubber (not to be confused with thermoplastic polyurethane) is either ether- (EU) or ester- (AU) based	Excellent abrasion resistance and tear strength Ester-based compound has better thermal- and abrasion resistance, while the ether-based polymer has better flexibility at low temperatures
Polyacrylic rubber (ACM)	A family of polymers with blends of ethyl and butyl acrylate repeat units. Other monomers may be included to adjust properties	Good resistance to weathering, ozone and UV light High thermal resistance (similar to fluorosilicones at lower cost) Poor resistance to hot water
Butyl rubber	Copolymer of isobutylene and isoprene	Good thermal stability and low gas-permeability Not suitable for petroleum-based fluids Good vibration- and shock-dampening abilities

Cost. Although costs can vary widely depending on compounding and processing, relative prices begin with nitrile and chloroprene as the least expensive, followed by EPDM and silicone. Polyacrylate, butyl rubber and HNBR are the next most expensive, then the fluorocarbons, TFE/P and finally fluorosilicones, which are at perhaps 15 times the relative cost of the least expensive materials. ■

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Facts At Your Fingertips

Pneumatic Conveying Flow Patterns

Department Editor: Scott Jenkins

Pneumatic conveying is a ubiquitous mode of conveying bulk solids in a wide range of industries, including chemicals, plastics, grain, food, agriculture, mining, power generation and cement, among others. The flow patterns within conveying lines depend on the properties of the materials being moved, the pressure drop across the conveying route and the velocity of the conveying gas. This one-page reference provides information about plotting relationships between these variables.

Zenz plot

The relationship between flow pattern (mode of conveying) and key operating variables (such as pressure drop, gas velocity and solids flowrate) for a given conveying layout is best represented by the system state diagram (Figure 1; often called a Zenz plot). Today's versions of the Zenz diagram typically plot the overall pressure drop against terminal gas velocity on a linear scale. In any pneumatic conveying system, each combination of bulk material characteristics and specific pipe-routing schematics will have its own unique characteristics, hence a system-specific state diagram. Overall pressure drop is used for the ordinate (*y*-axis). This diagram is independent of the feeding technology.

In the system state diagram, the lowest curve represents the pressure drop characteristics of single-phase (gas) flow in a conveying line. Here, the pressure drop is proportional to the square of gas velocity. When solids are introduced into the conveying line, additional energy is required to overcome losses due to friction, wall impacts, and to initially accelerate the particles and then reaccelerate them after bends or vertical lifts. These losses manifest themselves as additional pressure drop, which increases with rising solids flowrate.

Saltation velocity

If the conveying gas velocity is sufficiently high, then stable dilute-phase conveying conditions will prevail, where all particles are fully suspended in the conveying gas. As the gas velocity (or gas flowrate) is reduced, the pressure drop continues to decrease, even though the solids flowrate remains constant. Correspondingly, the flow pattern in the conveying line changes from fully suspended flow to stratified flow, with a higher concentration of particles in the lower section of the pipe. Eventually, the particles begin to fall out of suspension and begin to roll, slide and move along the bottom of the pipe. The gas velocity corresponding to this state of flow is called the saltation velocity, and the corresponding pressure drop shows a minimum in the characteristic curve. Operating conditions to the left of the pressure drop minimum will result in additional settling of particles (saltation), which leads to sluggish conveying behavior and may cause temporary plugging of the conveying line along with intense line vibrations.

Figure from Ref. [1]

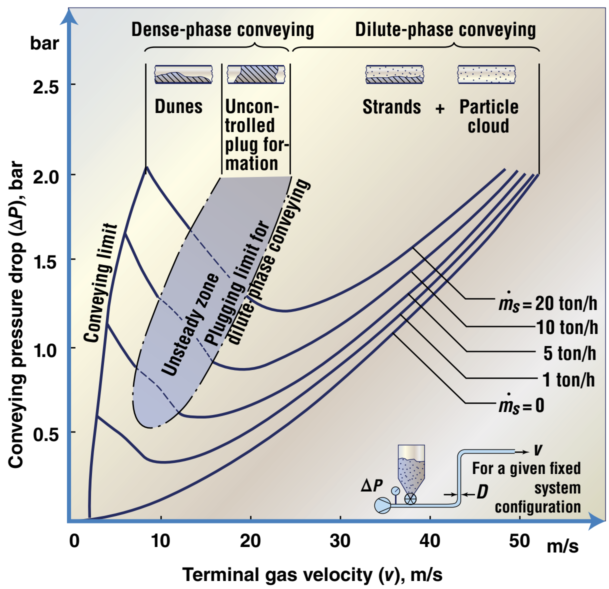

FIGURE 1. The state diagram of pneumatic conveying shows the relationships between key operating variables

Dense phase conveying

This unstable zone (shown in Figure 1) separates the dilute-phase from the dense-phase areas in the state diagram. If the conveying pressure required for stable conditions exceeds the available pressure from the blower, compressor or compressed plant air supply, then the conveying system will stall or plug. With further decreases in gas velocity, the zone of stable dense-phase conveying is reached — to the left of the unstable zone (that is, at lower gas velocities but significantly higher pressures).

The conditions that produce stable, dense-phase conveying are much more limited compared to those that produce dilute-phase conveying. Finally, the line shown furthest to the left in Figure 1 represents the termination of dense-phase conveying in the form of a stationary plug.

The zone of stable, dense-phase conveying is wedged between the unstable region and the conveying limit. The pressure required to move a slug of solids is significantly higher than that required for dilute-phase conveying at the same conveying rate — thus, most practical applications require the use of compressors.

Dense-phase conveying is often referred to as "slow-motion conveying." Not all high-pressure conveying systems will actually operate in dense-phase mode or in slow-motion conveying. One must pay particular attention to the system design, line stepping (that is, increasing the line diameter along the conveying length to reduce local gas velocity) and velocity profile, and manage the conveying gas, to achieve dense-phase conveying. ■

Editor's note: This "Facts at your Fingertips" column was adapted from the following article (Reference 1): Wilms, H. and Dhodapkar, S., Pneumatic conveying: optimal system design, operation and control, *Chem. Eng.*, Oct. 2014, pp. 59–67.

Sodium Lauryl Ether Sulfate Production

By Intratec Solutions

Sodium lauryl ether sulfate (also known as SLES and sodium laureth sulfate) is a clear and viscous liquid that is among the most important anionic surfactants. On an industrial scale, SLES is mainly produced by the ethoxylation of dodecanol, followed by the sulfation of the resulting ethoxylate and neutralization to the sodium salt.

Like other fatty alcohol sulfates and fatty alcohol ether sulfates, SLES has uses that are basically related to its surface-active properties. SLES molecules include both hydrophilic and hydrophobic functional groups. In fact, the possibility of altering those properties allows chemical processors to tailor these compounds to be used in a broad range of applications that demand good activity (that is, foaming and detergency), stability over a wide pH range, water solubility, chemical compatibility and so on. With such versatility, these chemicals are widely used in cosmetic products and in industrial cleaners.

The process

The following describes a process for SLES production from chlorosulfonic acid, lauryl ethoxylate and sodium hydroxide. Figure 1 presents a simplified flow diagram of the process.

Sulfation. Initially, the lauryl ethoxylate is batch-sulfated by cholorosulfonic acid. Both reagents are fed to a glass-lined stirred, jacketed reactor, with the acid being gradually added to the reaction. The sulfation is carried out at 25–30°C under vacuum, over about a period of 2.5 h. The gaseous HCl byproduct is led off the sulfation product, and directed to a scrubber downstream. The sulfation product is fed to the neutralization.

Neutralization. The sulfation product is fed to a neutralization vessel, where it is contacted with a 50 wt.% caustic soda solution, along with process water, for adjusting its active component. The neutralization reaction is carried out at a temperature below 45°C, generating a 70 wt.% sodium lauryl ether sulfate, which is further routed to packaging.

Scrubbing. The HCl evolved during the sulfation is fed to a scrubber, where it is absorbed into process water, generating a 33 wt.% hydrochloric acid solution byproduct.

Packing. SLES is packed in drums and then sent to warehouses for storage outside the battery limits (OSBL) of the facility.

Production pathways

SLES production is primarily based on the sulfation of lauryl ethoxylate, in such a way that different SLES manufacturing routes are basically related to different sulfating agents employed. Typically, chlorosulfonic acid, sulfur trioxide or oleum ($SO_3 \cdot H_2SO_4$) reagents are used for that purpose. Figure 2 presents different pathways for SLES production.

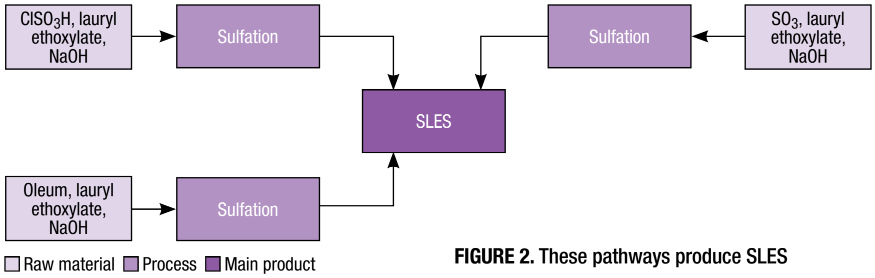

FIGURE 2. These pathways produce SLES

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce SLES was about $2,130 per ton of SLES in the second quarter of 2014. The analysis was based on a plant constructed in the U.S. with the capacity to produce 15,000 metric tons per year of SLES.

This column is based on the report "Sodium Lauryl Ether Sulfate Production – Cost Analysis," published by Intratec. It can be found at the following URL: www.intratec.us/analysis/sles-e11a. ■

Edited by Scott Jenkins

Editor's note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

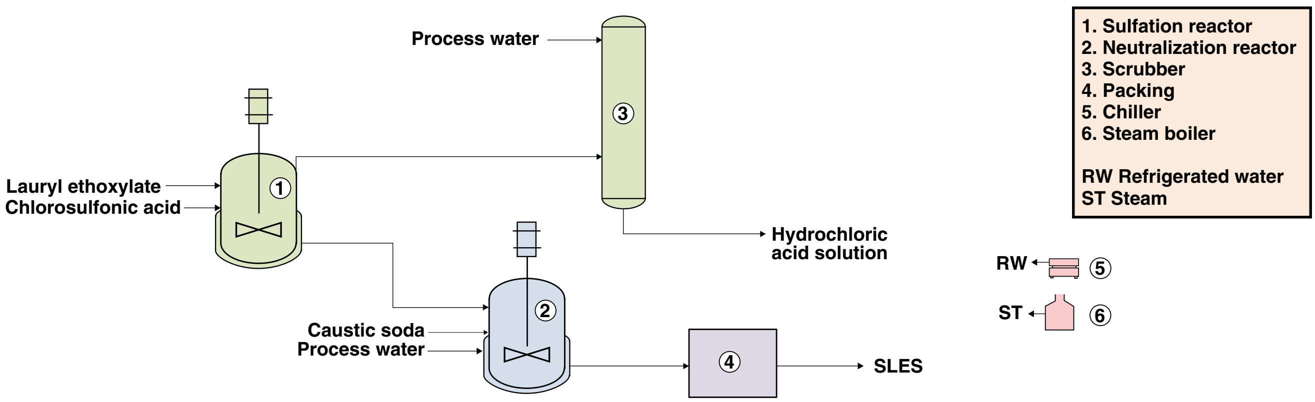

FIGURE 1. The diagram shows a process for producing sodium lauryl ether sulfate (SLES)

Photochemical Processes in Stirred Tank Reactors

A general overview of industrial photochemistry and the design of large-scale stirred-tank photochemical reactors

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IN BRIEF

PHOTOCHEMISTRY

STIRRED-TANK PHOTOCHEMICAL REACTORS

IRRADIATION AND ABSORPTION OF RADIATION

STIRRED-TANK REACTORS

AGITATOR DESIGN

MECHANICAL DESIGN AND SAFETY

Photochemical processes complement or may even substitute conventional (thermal) processes. The radiant energy initiates the reaction, for example by forming radicals, and in most cases, no thermal energy is needed to overcome the energy barrier according to Arrhenius' law. Photochemical reactions are usually kept well below 100°C, hence leading to far fewer side reactions and formation of byproducts than thermal reactions. Except for photocatalyzed processes, no expensive catalysts with their elaborate handling requirements are needed.

In most cases, photochemical processes are performed in immersion-type tubular reactors in which turbulence is achieved and maintained by circulating the reaction system or by the production or the introduction of gases. Only recently have stirred-tank reactors — still the "workhorse" of the chemical industry — been adapted to the requirements of photochemical processes (Figure 1). This article describes the basics of industrial photochemistry and the present state-of-the-art for the design of stirred-tank photochemical reactors.

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FIGURE 1. An inside view of a stirred-tank photochemical reactor (see also the cover photo for an impression of the size)

Photochemistry

For a conventional (thermal) chemical reaction, the rate, r, is given by the concentration c_x of the reactants A and B, and the rate coefficient k, which is intrinsic to a specific reaction, as given by Equation (1):

$$r = k \cdot c_A^{x_A} \cdot c_B^{x_B} \tag{1}$$

Where k follows Arrhenius' law (a list of all nomenclature is given in the box on p. 56):

TABLE 1. INDUSTRIAL PHOTOCHEMICAL PROCESSES, REACTIONS, PRODUCTS

Process	Product	Industry	Mechanism	Multiphase System
Chlorination	Intermediates, solvents, C-PVC, rubbers	Specialties, polymers	Radical	L-G L-G-S
Bromination	Intermediates	Specialties	Radical	L
Sulfoxidation	Intermediates, sulfonic acids, surface-active materials	Specialties, consumer products, polymers	Radical	L-G
Sulfochlorination	Intermediates, sulfonic acids, surface-active materials	Specialties, consumer products, polymers	Radical	L-G
Nitrosylation	Intermediates, Nylon 6 and 12	Specialties, polymers	Radical	L-G-S
Hydro-dimerization	Intermediates	Specialties, agrochemicals	Radical	L
Oxidation	Intermediates, surface-active materials	Specialties, perfumes, pharmaceuticals	Radical, sensitized, catalytic	L L-G G-S L-G-S
Isomerization	Intermediates	Specialties, pharmaceuticals	Electron density distribution, sensitized	L
Cycloaddition, electrocyclic reactions	Intermediates	Specialties, pharmaceuticals	Electron density distribution, sensitized	L
Polymerization	Polymers	Specialties, polymers	Radical, ionic, catalytic	L L-G L-S L-G-S

Note: L = liquid phase, G = gas phase, S = solid phase

$$k = A \cdot e^{-E_A/RT} \quad (2)$$

At ambient temperature, k is too small for most reactions to get them started. To raise it to an economic rate, the temperature T must be increased. Therefore, most industrial reactions run at higher temperatures. High temperatures not only enhance the desired reaction, but also side reactions, leading to undesirable byproducts or to thermal decomposition of reactants, intermediates and products. Both entail costs for starting materials, waste treatment and an increased effort to purify the product.

Catalysts allow high conversion rates at lower temperatures as they reduce the activation energy, E_A. But catalysts involve costs for their procurement or make up, handling, feeding, separation and recovery or disposal.

Process initiation by radiant energy allows for running reactions independently of temperature and in most cases, well below 100°C and without a catalyst. Photocatalysts for specific reactions are not used to decrease E_A, but to impose a specific mechanism of chemical transformation.

The absorption of electromagnetic radiation of an appropriate wavelength promotes the reactant molecule from its ground state to an electronically excited state, from which it subsequently undergoes a mostly specific chemical transformation to a stable product or to a reactive intermediate capable of initiating a second thermal reaction. The most relevant industrial photochemical processes and their primary mechanisms are listed in Table 1 [*1*].

A description of the immense diversity of the reaction mechanisms would be beyond the scope of this article. For detailed information, the interested reader is referred to the literature [*1–9*]. Representative for the predominant radical mechanisms is the photochemical halogenation: electronic excitation of ground-state molecules Cl_2 or Br_2 leads to a dissociative state generating the respective radicals Cl· or Br· that may add to C=C double bonds or abstract a hydrogen atom [*1*]. The latter is shown in Figure 2.

λ = 250-450 nm $\quad Cl_2 \xrightarrow{h\nu} 2\,Cl^\bullet$

Chain propagation $\quad Cl^\bullet + R\text{-}H \longrightarrow {}^\bullet R + HCl$

$\quad {}^\bullet R + Cl_2 \longrightarrow R\text{-}Cl + Cl^\bullet$

Chain termination by recombination of radicals

$Cl^\bullet + Cl^\bullet \rightarrow Cl_2 \;/\; Cl^\bullet + {}^\bullet R \rightarrow R\text{-}Cl$

FIGURE 2. In the reaction mechanism of chlorination, light is first absorbed by Cl_2 to form Cl· radicals, which subsequently substitute a hydrogen in a hydrocarbon compound

Stirred-tank photochemical reactors

Large-scale industrial applications of photochemical reactions have been known for more than 100 years, when first attempts to up-scale photochemical chlorinations were rendered possible by the development of mercury vapor lamps [*10*]. Immersion-type photochemical reactors [*1*] were conceived to profit from the radiation emitted 360 deg radially from cylindrically shaped light sources. Such processes required modest knowledge in the domain of photochemistry, but proved to be a real challenge for engineers. Challenges include concerns primarily over the corrosion-resistant materials (for example, in the case of chlorinations), the new design of mechanically resistant quartz-metal interfaces and the design of new concepts ensuring high-turbulent conditions in the presence of fragile lamp installations. Particular attention had to be devoted to handling the exothermicity of chain reactions.

The progress in the domains of physical and theoretical chemistry also fostered the understanding of the fundamentals of photophysics and photochemistry and opened a wide field of applications.

The present status of photochemical engineering provides technical and ecological answers for practically all up-coming projects and also allows a better economic analysis and control of costs of production and maintenance. Such viable answers need the cooperation of dedicated specialists in the domains of photochemical, materials, chemical and mechanical engineering.

A new concept of a stirred-tank photochemical reactor (Figure 3) has been developed mainly for multiphase reactions (Table 1). It can be operated batchwise, as fed-batch or continuously as a continuous stirred tank reactor (CSTR). The aspect ratio H/T_D of the tanks is 1 to 1.5, reactor volumes range from 1 to 50 m^3. Mixing provides the circulation of the substrate to the radiation source, the turbulence to disperse and dissolve a reactive gas and prevents solids from sedimentation. The glass or quartz wells housing the radiation sources are inserted through nozzles on the tank head and fixed to the wall or to the tank bottom. The upper end of the well on top of the tank nozzle has connecting devices for the electric power and the cooling medium of the radiation sources. The number of radiation sources is restricted by space constraints on the tank head; large tanks may contain up to 20 lamps. The heat of the reaction is removed by cooling through the tank wall with jacket or half pipes. If that is not sufficient, additional coils can be installed within the space between the wells and the wall. Cooling by evaporating solvents could be another alternative.

Photochemical process development usually starts with laboratory-size equipment, including commercially available reactors with which homogeneous liquid reaction systems, as well as heterogeneous gas-liquid, liquid-solid and gas-liquid-solid systems may be investigated (Figure 4). The objective of laboratory experiments is twofold: 1) choosing and optimizing the unit equipment and, in particular, the geometry of the photochemical reactor; and 2) investigating optimal conditions in terms of rate and specificity of the process.

Absorption spectra of the photochemical reactant and the substrate mixture allow one to determine the wavelength(s) of excitation and to choose the corresponding radiation source. The selection of the latter and its power depends on the required range of excitation, the specificity of the reaction and the projected mass of production per unit of time.

The quantum yield is an additional design parameter to be considered when there are restrictions in the scaleup, for instance the geometrical parameters or the electrical power. The quantum yield represents the efficiency of the irradiation, and can be defined as the number of moles of reactant converted per number of moles of photons absorbed over the same time period

FIGURE 3. This stirred-tank photochemical reactor incorporates eight light sources

and in the reference volume.

Additional parameters to consider are the residence time within the irradiated volume, the spectral range of excitation, temperature, substrate concentrations, solvent effects and reaction kinetics — also of subsequent thermal reactions and safety considerations.

The scaleup to and the design of the production plant on the basis of such laboratory testing involves, in most cases, further investigations in pilot reactors with typical volumes of 20 to 200 L. The engineer must consider and tune the following parameters, which are described in the following sections:

- Adaptation of the photochemical reactor to the type and number of radiation source originally chosen and its/their electrical power calculated from the exitance necessary to produce the projected mass of product per unit of time
- Agitation
  - Optimized residence time in the irradiated reactor volume for homogeneous reaction systems and high circulation rates of particles and slurries to the light source to compensate for the short penetration depth of radiation
  - Optimized gas dispersion and gas-liquid mass transfer
  - Maintenance of suspension of solids
- Heat transfer (reaction enthalpy and radiation sources) to maintain the process temperature
- Mechanical integrity of the wells housing the radiation sources
- Corrosion-resistant materials of construction
- Safety aspects concerning radiation, radiation sources, corrosion and toxicity of chemicals

Irradiation and absorption

A new and reliable design of an agitated photochemical reactor with an elaborated concept of agitation and fixing of the wells with corrosion-resistant materials is, at present, the answer to an increasing demand for the processes summarized in Table 1. Figure 3 depicts the arrangement of a given number of light sources inserted into the required cooling and protection tubes (wells) that are located and secured among each other as well as connected to the reactor wall. Given the fact of a relatively limited chain reaction, as in the case of the chlorination of polymer granulates (for example, chlorinated polyvinyl chloride; C-PVC), and the rather low quantum efficiencies of most of the investigated photochemical reactions in heterogeneous media, a rather high incident radiant power density, I_0, is required for a large production scale.

Up to the present, mercury (Hg) medium-pressure arcs are mostly used for the excitation within the ultraviolet and visible (UV/VIS) spectral domain of wavelengths >250 nm [*1*]. Because of their operating temperature of approximately 900°C, water-cooling and in some cases the implementation of insulating vacuum spaces are necessary.

Hg-arcs are contained in cylinders of borosilicate glass or quartz and emit over their entire circumference. They provide a broad line-spectrum with peaks of various intensities (Figure 5). Some light-emitting diodes (LEDs) emit quasi-monochromatic radiation (Figure 5) and may be used for photo-

chemical processes, where high reaction specificity is required. The substitution of Hg-arcs exhibiting a radiant efficiency of approximately 30% by LED-arrays for large-scale applications needs further development, mainly for reasons of their implementation in wells, their electronic controls and the cooling of multiple and large arrays. Their unilateral emission and arrangement on a support does not allow for a quasi-homogeneous emission over the entire circumference of the well.

Commercially available medium-pressure Hg arcs are standardized in size, and have electric power in a range of 5 to 60 kW (Figure 6). Specific know-how is needed for the design of the electric power connection and supply, as well as for the cooling medium passing through the head of the well, which is bolted onto the tank nozzle.

Even if the outer protection tube (made of glass or quartz) with its connection to the tank is a reliable and proven component, its breakage should be considered in the risk analysis. As the components of the reaction system are usually hazardous or corrosive (or both), such a rare event has to be detected by monitoring, and the leakage must automatically be collected in a containment. Those emergency procedures are fixed in detail through the HAZOP (hazard and operability study) of the reactor.

Relevant for the design of a photochemical reactor is the fact that the incident radial power, I_0, is not constant throughout the reactor volume containing radiation-absorbing components. Its attenuation is due to chromophores, that is, functional groups of molecules absorbing radiation of given wavelengths [*1, 2*] and resulting in its exponential decrease with distance *x* from the source within the absorbing medium, as described by the Lambert-Beer law, Equation (3):

$$\frac{I}{I_0}(\lambda) = e^{-\kappa(\lambda)\cdot c\cdot x} = e^{-B(\lambda)} \quad (3)$$

The drop of the relative radiant power, I/I_0, with distance *x* from the entrance of the radiation is shown in Figure 6. The molecule-specific molar absorption coefficient, κ, depends on wavelength, λ. The concentration, *c*, of the light-absorbing substance is simplisticly assumed to be constant over the whole distance of the optical path. The spectral absorbance $B(\lambda)$ is an additive property, which means for mixtures containing more than one absorbing compound, $B(\lambda)$ is expressed as:

$$B(\lambda) = [\kappa_1(\lambda)\cdot c_1 + \kappa_2(\lambda)\cdot c_2 + \cdots]\cdot x \quad (4)$$

Usually, decadic molar absorption coefficients $\varepsilon(\lambda)$ are determined in UV/VIS spectrophotometers and can be transformed into Naperian molar absorption coefficients by $\kappa = 2.303 \cdot \varepsilon$.

Figure 7 demonstrates, in principle, one of the most important obstacles to be surmounted while up-scaling photochemical reactions: depending on $B(\lambda)$ of the substrates and products, either their concentration or the

Peschl Ultraviolet, MPDS-EVO

FIGURE 4. Laboratory-scale units can be used for the investigation and optimization of the specificity and rate of a photochemical process

reactor volume exposed to radiation could be severely limited in order to irradiate the total volume of the reactor. With lifetimes of electronically excited molecules of 10^{-6} to 10^{-12} s, moving these excited molecules by convective transport toward the non-irradiated volume of the reactor is impossible. Nevertheless, these constraints may be avoided or at least lessened, in particular in the scaleup of photochemical processes in stirred-tank reactors by the following measures:

- Adapting the concentration(s) of the absorbing component(s) of the reaction system to the given optical path of the reactor
- Increasing the irradiated volume with a larger diameter of the well, maintaining its optical path, adapting the radiant power density of the radiation source and optimizing the flux of the reaction system
- Increasing the number of radiation sources, with the maximum being defined by the space on the tank head, maintaining their exitance
- Adapting the agitator design for maximum

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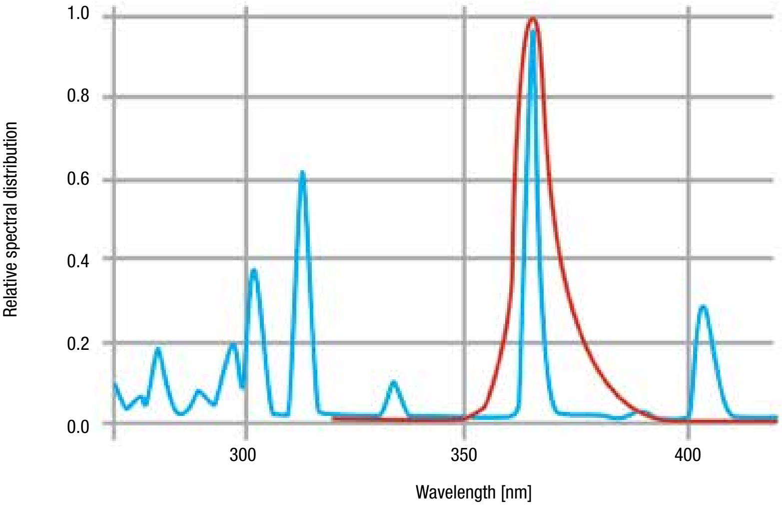

FIGURE 5. The emission spectrum of a medium-pressure mercury arc lamp is shown in blue. A light-emitting diode (red curve) emits quasi-monochromatically, here at 365 nm (ultraviolet)

FIGURE 6. Medium-pressure Hg-arcs are available with different electrical power ratings (left). The photo on the right shows the well head of a 25 kW, medium-pressure Hg-arc for the connections to the electric power supply, cooling medium and inert gas

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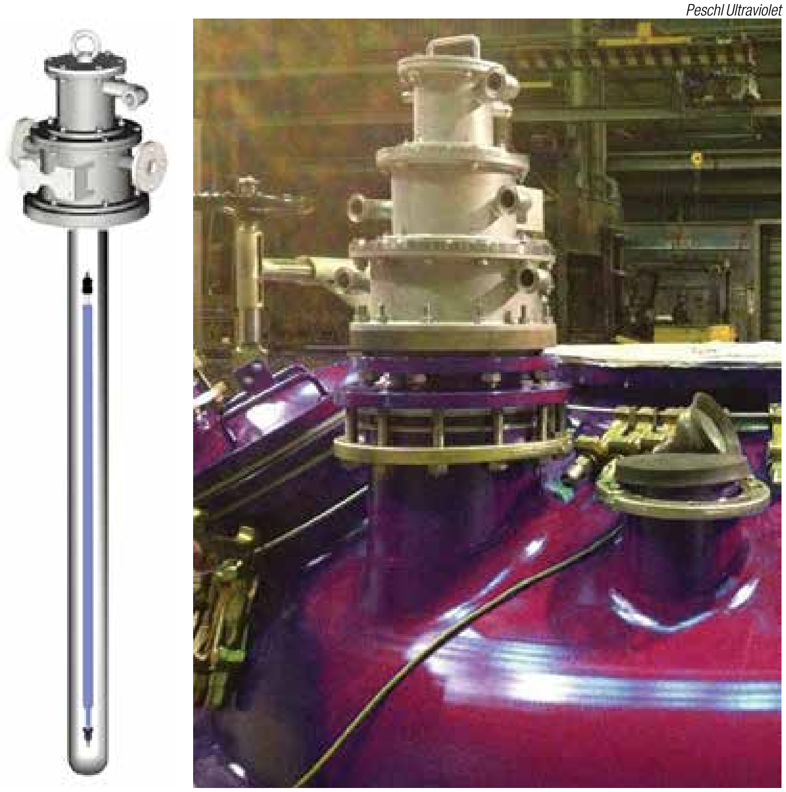

and homogeneous pumping efficiency with frequent renewal of the fluid in the irradiated zones

- Multiplying the number of reactors (numbering up versus scaling up)

Evidently, Lambert-Beer's law cannot be applied to heterogeneous reaction systems, because the incident radiation will not only be absorbed, but also scattered and reflected by particles or bubbles. In heterogeneous media, the incident radiant power is attenuated with distance *x*, according to Equation (5):

$$\frac{I}{I_0}(\lambda) = e^{-E(\lambda)\cdot x} \quad (5)$$

Where $E(\lambda)$ is the extinction coefficient, usually defined as the sum of the absorption $\mathrm{K}(\lambda)$ and scattering $S(\lambda)$ coefficients:

$$E(\lambda) = \mathrm{K}(\lambda) + S(\lambda) \quad (6)$$

For dispersions, $\mathrm{K}(\lambda)$ and $S(\lambda)$ may be determined experimentally by spectrophotometric methods [*11, 12*].

Stirred-tank reactor

Mixing is important to move the reactants into, and to remove reaction intermediates and products of the overall reaction from, the irradiated volume. The number of contacts *z* of a fluid element with the irradiated zone correlates with the impeller pumping rate, $\dot{q}$, and the volume of the tank, *V*, as given by Equation (7):

$$\frac{z}{t} \sim \frac{\dot{q}}{V} \quad (7)$$

For scaleup with geometric similarity and constant specific impeller power per volume *P/V*, the pumping rate per volume is reduced with reactor size, represented by the tank diameter T_D as length scale factor [*13*]

$$\frac{\dot{q}}{V} \sim \frac{1}{T_D^{2/3}} \quad (8)$$

Consequently, by increasing the reactor volume, all of the fluid elements pass through the irradiated volume less frequently, and the photochemical reaction progresses more slowly. This decrease of the overall reaction rate can be partially compensated: the same impeller type with a larger impeller diameter *D* provides larger pumping rates even when operated at lower speed to comply with the same shaft power.

$$\dot{q} \sim D^{4/3} \quad (9)$$

Another option to increase the irradiated volume would be the extension of the well's circumference combined with an increase of radiant power to keep the exitance constant. Finally, the irradiated volume may also be increased by raising the number of radiation sources.

Particular attention must be paid to the hydraulic load on the wells created by intense or vigorous agitation. The oncoming flow generates pressure, *p*, on the quartz or borosilicate tubes that may be estimated by Equation (10) [*14*].

$$p = c_w \cdot \frac{\rho}{2} \cdot v^2 \quad (10)$$

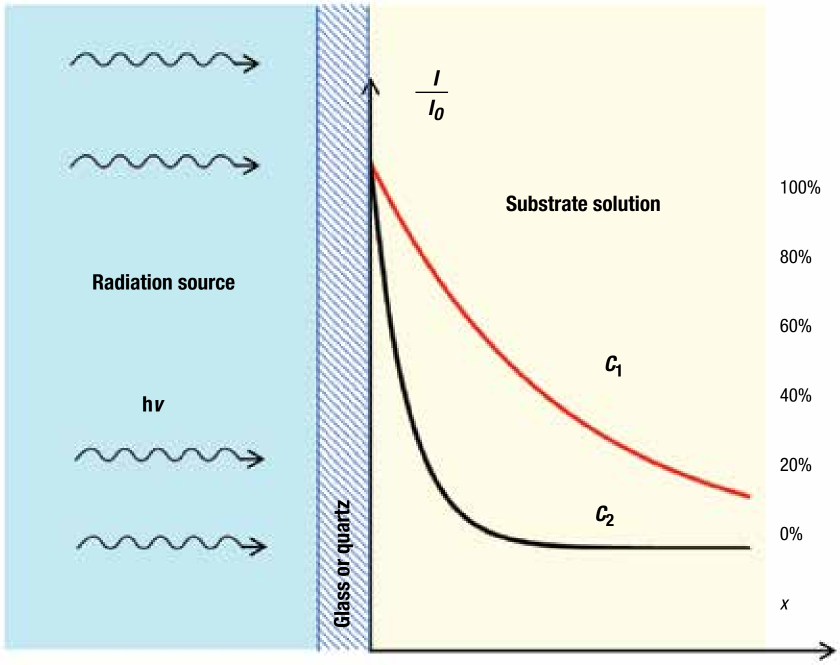

FIGURE 7. This graph of the Lambert-Beer law shows the decrease in radiant power with distance x due to absorption ($c_2 > c_1$)

This pressure is not constant, it fluctuates substantially around its mean value due to the velocity fluctuations of the turbulent flow. Local velocities may be calculated by computational fluid dynamics (CFD), and the corresponding flow simulation shows their variation in the vicinity of the tubes (Figure 8). CFD may also be used to optimize the impeller arrangement to equalize the flow around the inserted wells avoiding stagnant zones.

Additionally, the high energetic vortices from the turbulence spectrum, vortex shedding according to the Karman principle and blade passing frequencies of the impeller cause the lamp units to vibrate at its resonance frequency, if it coincides with the exciting frequency [*13*]. The vortex shedding frequency, *f*, may be evaluated from the inflow velocity *v*, the tube diameter *d* and the Strouhal number Sr [*15*]:

$$f = \frac{Sr \cdot v}{d} \quad \textbf{(11)}$$

The Strouhal number assumes characteristic values for different geometric forms, such as cylinders. The blade passing frequency f_B is calculated from the impeller speed, *n*, and the number of impeller blades, z_B:

$$f_B = n \cdot z_B \quad \textbf{(12)}$$

The concept used for the fixation and stabilization of the well's housing ensures that the natural frequency of the tubes will be sufficiently higher than the exciting frequencies. Calculations by finite element analysis (FEA) and modal analysis must also take into account that the fluid-structure coupling leads to conditions where the liquid surroundings of the wells reduce the natural frequencies to approximately half [*13*]. The challenge linked to the construction of the fixation is threefold:

1. The well holders must be designed in a way that gaps between holder and tube are excluded to avoid space for vibrations.
2. Stress on the mounted quartz or glass tubes must be excluded, even if the tubes are not perfectly straight upon delivery and nozzles and holders are not perfectly aligned due to tolerances in the tank manufacturing process.
3. The support must allow for the thermal dilatation of the tubes without stress.

Agitator design

Beside the permanent renewal of the fluid within the irradiated zones, as described above, stirring of the reac-

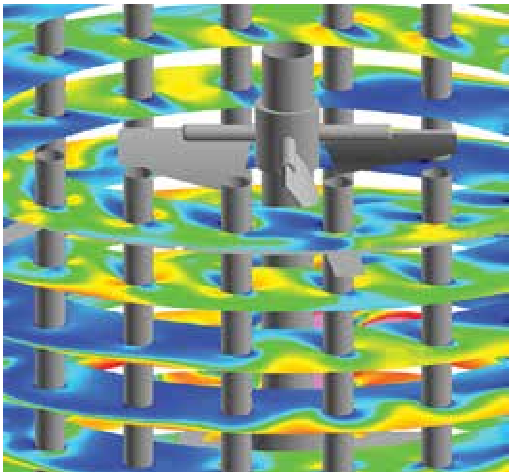

FIGURE 8. Shown here are horizontal sections of flow velocities at the well housing of radiation sources in a stirred-tank photochemical reactor

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tion system must accomplish the following fundamental tasks:

Blending. In order to ensure equal physical and chemical reaction conditions in all areas of the tank, temperature and concentration gradients must be balanced. In the turbulent flow range, as is always the case in this type of reactor, the blend time number, that is, the product of stirrer speed, n, and blend time, θ, is constant [*13*]:

$$n \cdot \theta = constant \quad (13)$$

Identical mixing times and homogeneities on all operational scales (laboratory, pilot, production) are only achieved if n is kept constant for geometrically similar designs of the reactor unit. However, if n is kept constant, the required impeller power, P, would grow uneconomically high with $P \propto D^5$, as seen by Equation (14):

$$P = N_P \cdot \rho \cdot n^3 \cdot D^5 \quad (14)$$

Longer mixing times at lower speed would hence result, but can at least partially be compensated by a reasonable combination of type and number of impellers that would match with the impeding effects of the tank internals. The concept of the blend time fits exactly in with the model of the impeller pumping rate [see Equations (7–9)]: in order to achieve a defined degree of homogeneity, a defined number of recirculations of the tank content is required.

Suspending. Educts, catalysts and products of photochemical processes are often solid components (for example, C-PVC,

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FIGURE 9. The combined gassing impellers provide maximum mass transfer with the primary disperser (Phasejet) below the self-inducing turbine (Gasjet)

TiO_2, oximes or polymer particles) that must be prevented from settling and be distributed as homogeneously as possible within the tank. The settling rate of the solids together with the solids concentration is relevant for the design of the agitator. The concentration of solids, their particle-size distribution, the liquid viscosity and the density difference between solids and liquid must therefore be known. Organic solids exhibit generally low densities (for instance, ~1,400 kg/m^3 for PVC and 1,500–1,600 kg/m^3 for C-PVC, depending on product specifications [*16*]) and their suspending should not be a critical issue.

Floating may at times be observed in the case of poorly wetting solids during concurrent gassing or de-gassing of a reaction byproduct, such as HCl in chlorinations (Figure 2). Since solid particles adhere to gas bubbles, they may rise to the liquid surface and develop with the foam into a stable layer. A surface impeller would break up the foam and minimize the layer by forcing the particles down into the turbulent reaction system.

Gas dispersion. A large fraction of the photochemical processes are based on the photochemical reactivity of bromine, chlorine, nitrosyl chloride, oxygen or sulfur dioxide that may be introduced into the reaction systems in liquid or in gaseous form. Gases must be dispersed as finely as possible to maximize the rate of dissolution in a given solvent or solvent mixture. The combined gassing system, as depicted in Figure 9, provides optimum mass transfer [*17*]: controlled by the

tank pressure, the reactive gas may be injected and spread underneath the primary disperser. The fraction of the gas that is not immediately dissolved rises into the head-space of the reactor above the liquid level and is drawn back into the liquid by way of the upper self-inducing turbine. For slow photochemical reactions, the self-inducing turbine would suffice on its own to achieve sufficient transfer rates if the gas would be fed into the reactor from the top of the tank (Figure 3). Such an arrangement would reduce expensive piping of corrosion-resistant material within the reactor.

Heat transfer. Heat from the exothermic processes, from the stirring and emitted by the radiation sources (despite cooling by transparent liquids circulating within the wells), must be removed from the reactor through the tank wall with a jacket or half-pipe coils. However, with low reaction temperature, the driving temperature gradient with the coolant is rather low. Installation of heat-exchangers within the reactor is possible, but limited by the space required for the lamps and by the additional costs for corrosion-resistant materials. Chilled water or cooling brine may be used to collect the residual heat of the process. The heat-transfer coefficient for the stirred side is calculated based on the known dimensionless numbers contained in Equation (15):

$$Nu = f(Re, Pr, Geo) \qquad (15)$$

Where:
Nu = Nusselt number
Re = Reynolds Number
Pr = Prandtl number
Geo = factor considering the impeller type and the geometry of the heat-exchanging surface in case of cooling coils, as laid out in detail in Ref. 13.

Mechanical design and safety

Many substances involved in photochemical reactions (Table 1) are highly corrosive, which precludes the use of conventional stainless steels. The material of construction of the product-wetted parts of the agitator (impeller, shaft, mounting flange and mechanical seal) and lamp holders must be, for example, nickel-based alloys, such as Hastelloy, or titanium. Tanks may be made of, or cladded with, these materials, or made of glass-lined carbon steel.

The measures for a safe operation of the glass or quartz wells with the lamps have been described previously. Given the toxic and corrosive properties of some of these reaction systems and the emanating liquids, gases or aerosols, the sealing of the rotating agitator shaft is a fundamental safety element [*18*]. Even if pressure and temperature levels are moderate during most photochemical processes, only double-acting mechanical seals or hermetically sealed magnetic couplings are suitable options to ensure complete separation of the reactor content

from the environment.

The double-acting seals hold a sealed chamber between two seal-ring pairs that is filled with a barrier liquid (Figure 10). Pressurization of the latter creates a secure separation between process space and the environment. The pressurized barrier liquid provides a hydrodynamic lubrication film between the surfaces of the rotating and the stationary rings, thus providing the necessary sealing function. As long as the pressure in the sealing chamber exceeds the pressure of the chemical process, the content of the tank cannot pass through the mechanical seal. In the rather unlikely case of a total failure of one of the pair of rings, the subsequent seal pressure drop would lead to immediate shutdown procedures. Until completion of such a procedure, the second seal pair will assume the seal function.

The pressure within the seal chamber can be held constant with pumps and pressure accumulators overlaid with gas. Alternatively, the pressure of the seal-liquid may be set to a defined value by a pressure compensator, as shown in Figure 10. The pressure compensator is equipped with a piston and exposed on one side to the reactor pressure. The piston area on the opposite side is reduced by the cross section of the piston rod, thus creating a higher pressure on the seal liquid when in a balanced state. The pressure ratio corresponds to the ratio of the two piston areas. With such a device, the seal pressure is always maintained at a higher level than that of the chemical process, without external energy, measurement or control devices.

The cylinder position can be transmit-

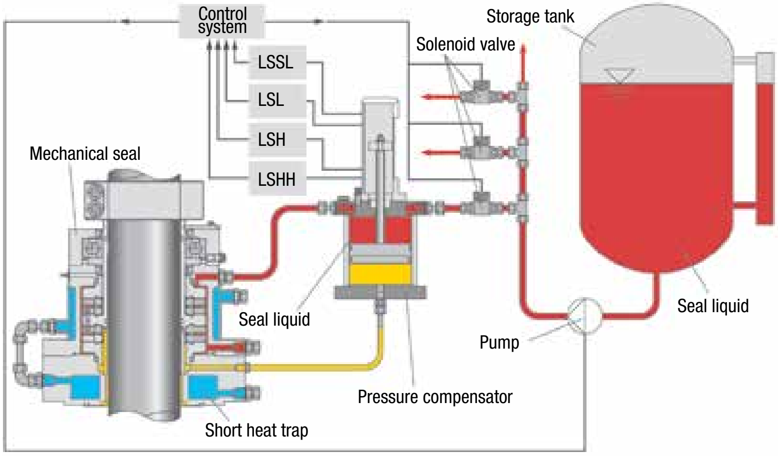

FIGURE 10. Shown here is a double-acting mechanical seal with pressure compensator, filling level monitor and central supply unit for multiple seals [*13*]

NOMENCLATURE

A	Arrhenius coefficient
$B(\lambda)$	Spectral absorbance, –
c_p	Specific heat, J/kgK
c_w	Drag coefficient, –
c_x	Concentration of component x, mol/m^3
d	Tube diameter, m
D	Impeller diameter, m
E_A	Activation energy, J/mol
$E(\lambda)$	Spectral extinction coefficient, m^{-1}
f	Frequency, s^{-1}
f_B	Blade-passing frequency, s^{-1}
H	Tank height, m
I_0	Incident radiant power, W/m^2
I	Radiant power, W/m^2
k	Reaction rate constant, s^{-1} (for 1st order)
$K(\lambda)$	Absorption coefficient, m^{-1}
n	Impeller speed, s^{-1}
p	Pressure, N/m^2
P	Impeller power, W
$\dot{q}$	Impeller pumping rate, m^3/s
r	Conversion rate, mol/m^{3}s
R	Universal gas constant, J/molK
$S(\lambda)$	Scattering coefficient, m^{-1}
t	time, s
T	Temperature, K
T_D	Tank diameter, m
v	Flow velocity, m/s
V	Volume, m^3
x	Length scale, m
x_i	Reaction order for reactant i
z	Number of contacts of a fluid element with the irradiated zone, –
z_B	Number of impeller blades, –
α	Heat-transfer coefficient, W/m^{2}K
ε	Molar absorption coefficient, m^2/mol
η	Dynamic viscosity, Pas
θ	Blend time, s
κ	Molar absorption coefficient (Naperian), m^2/mol
λ	Wavelength, m
λ	Thermal conductivity (in Nu and Pr), W/mK
ρ	Density, kg/m^3

Dimensionless numbers

$N_P = \frac{P}{\rho \cdot n^3 \cdot D^5}$	Power number
$Nu = \frac{\alpha \cdot T_D}{\lambda}$	Nusselt number
$Pr = \frac{\eta \cdot c_p}{\lambda}$	Prandtl number
$Re = \frac{n \cdot D^2 \cdot \rho}{\eta}$	Reynolds number
$Sr = \frac{f \cdot d}{v}$	Strouhal number

ted to the process control system hence allowing for automatic refill of the barrier liquid in case of operational leakages in the range of the level switch position low/high (level switch low/level switch high; LSL/LSH). Monitoring the frequency of refills provides information about the state of wear of the seals. One refill unit can supply several agitators. The redundant switches (level switch low low/level switch high high; LSLL/LSHH) provide additional safety for this fundamental function.

Concluding remarks

Photochemical processes break customary rules of reactor engineering and design and

have opened new or alternative pathways for the synthesis of new compounds and materials and their production on an industrial scale. New concepts of stirred-tank photochemical reactors, of the well fixation, as well as of new material combinations provide for their use in particular for processes starting in, or resulting in, a heterogeneous phase. The stirred-tank reactor, with its robust and flexible operation characteristics, also allows for batch, fed-batch and continuous operation.

Modern tools, such as numerical flow simulations (CFD), optimize the mixing process for multi-phase fluids, and finite element analysis (FEA) provides a reliable and economic design, even for critical materials, such as glass and highly corrosion-resistant alloys. Apart from new reactor designs, photochemical technology has made fast and profound progress in the domains of radiation sources and *in situ* photometric analysis. On a production scale, operational safety aspects — techniques of lamp fixation and sealing, electrical power control, monitoring of the process media and explosion-proof design — withstand any critical review. ■

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Performance Prediction for Industrial Boilers

Understanding boiler performance calculations can allow engineers to improve the operation of their facility's steam system and better engage with boiler-system vendors

Viswanathan Ganapathy
Boiler consultant

IN BRIEF

Chemical plants, petroleum refineries, power plants and cogeneration systems use oil-and-gas-fired steam generators, fluid heaters and waste-heat boilers of various types. Understanding how a boiler behaves with variations in parameters such as capacity, fluegas flow, inlet gas temperature or steam pressure can help plant engineers evaluate boilers better and understand why failures occur in crucial boiler components, such as superheaters, evaporators or economizers. Also, better understanding of boiler behavior can help plant engineers identify the reasons for decreases in efficiency. Figures 1 and 2 show heat-recovery steam generators (HRSGs) of natural- and forced-circulation designs behind gas turbines. Figure 3 shows a typical fire tube boiler used in a chemical plant and Figure 4 shows an oil-and-gas fired steam generator.

In many of today's cases, plant engineers rush to the vendor who supplied the equipment to ask opinions and get repair help, even if the boiler component is only experiencing minor performance problems. In this scenario, the vendor company is not likely to find faults with its own equipment design, even if there are flaws present. Rather, the vendor is likely to divert the attention of the plant engineers to

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FIGURE 1. Shown here is a modular heat-recovery steam generator (HRSG) system at a chemical manufacturing facility

the operations group or to the plant operating parameters. In other cases, the plant may not get a timely reply from the equipment vendor if the problem occurs several years after the equipment is installed.

Because boiler calculations are quite involved, many plant engineers are unable or unwilling to undertake them on their own. For many engineers, the basic heat-transfer principles covered in university degree programs are forgotten once they leave the institution behind for an industry job. This article

NOMENCLATURE

A	Surface area, ft^2 (subscripts i and o refer to inside and outside)
C-factor	Thermal conductance factor C_{min}/C_{max}
C_{min}, C_{max}	$(WCp)_{min}$, $(WCp)_{max}$
Cp	Specfic heat (subscript g for gas, s for steam, w for water)
d	Tube diameter, in. (subscript i for inside)
F_g	Factor considering gas properties used in heat transfer coefficient calculation
h	Heat transfer coefficient, Btu/ft^{2}h°F (subscripts i for inside, o for outside, c for convective, n for non-luminous)
K	Constant used in simplified equations considering tube geometry data (subscript m denotes thermal conductivity of tube metal at operating temperature)
k	Thermal conductivity of fluid, Btu/ft h°F
T	Temperature of hot fluid, °F (subscripts 1 and 2 indicate temperature at inlet and exit, respectively)
t	Temperature of cold fluid, °F (subscript s is for saturation temperature)
ΔT	Temperature difference, °F (log-mean temperature difference, LMTD)
U	Overall heat-transfer coefficient, Btu/ft^{2}h°F (subscripts i and o for inside and outside, c for corrected)
ε	Effectiveness, used in NTU method
η	fin effectiveness, fraction
Q	Duty, Btu/h (subscripts c for convective, r for external radiation, n for non-luminous)
W	Total flow, lb/h (subscripts i for inside, o for outside, h and c for hot and cold fluids)
w	Flow per tube, lb/h

is written to help process engineers perform basic boiler calculations and to help engineers apply heat-transfer and energy-engineering principles to understand and improve the operation of their plant's steam system.

Using the simplified approach outlined in this article, process engineers can predict the thermal performance of boiler components, including superheaters, evaporators, economizers, fluid heaters or HRSGs of fire-tube or water-tube types, with ease and with reasonable accuracy. Plant engineers can then confirm their predictions using field measurements. These procedures may also be used to make minor modifications to existing equipment at a later date, when operating parameters are changed or the plant is upgraded.

While major modifications to the boiler may require help or advice from the equipment vendors, performing the calculations presented here will allow plant engineers to quickly get an idea of the performance or duty of the boiler and its components. Knowledge of these calculations will help plant engineers in the future as well.

During interactions with various facilities, I have suggested that plants develop a team of process engineers who specialize only in boiler-related calculations, in an effort to determine if the field data of steam-generating equipment are reasonable and whether or not they can be confirmed by thermal calculations. This type of specialized team can also develop calculation modules or computer codes to check if there are significant deviations from normal operating parameters for every boiler component in the plant. These calculation modules can also be used to determine whether fouling is present.

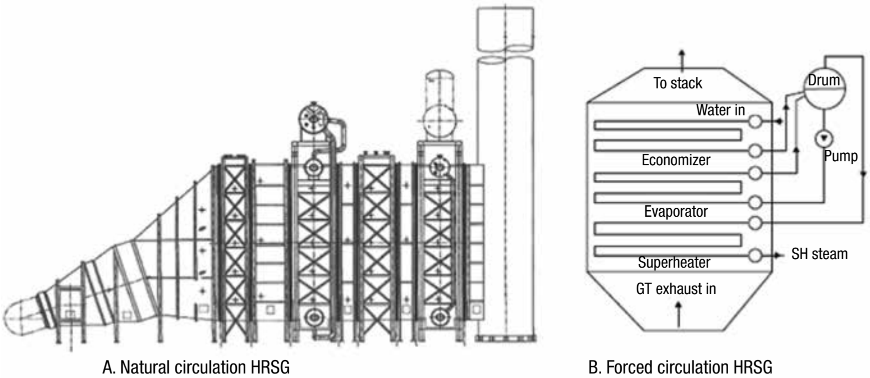

FIGURE 2. The diagram shows the components of natural-circulation HRSG and a forced-circulation HRSG

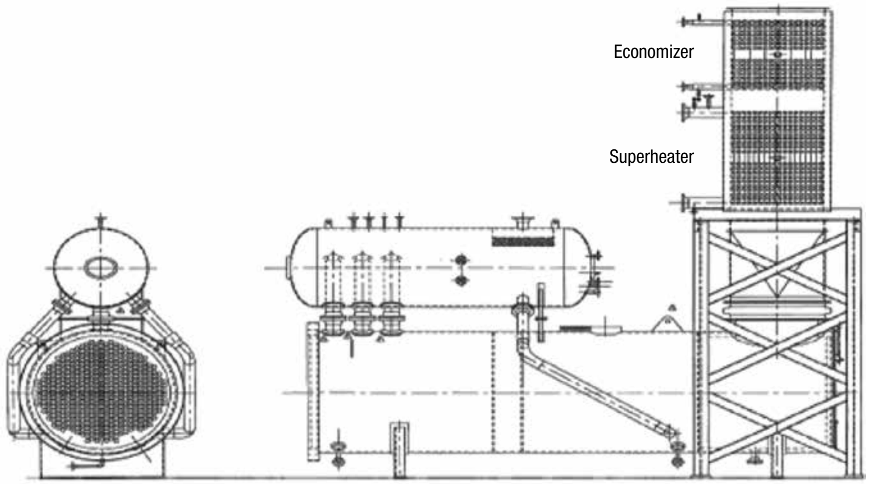

FIGURE 3. This diagram depicts a typical fire-tube boiler that would be used in a chemical plant

TABLE 1. STEAM GENERATOR TUBE GEOMETRY DATA

	Screen	Final superhtr.	Pry superhtr.	Evaporator	Economizer
Tube O.D., mm	50.8	50.8	50.8	50.8	50.8
Tube I.D., mm	44.0	43.0	43.0	44.0	44.0
Fins/m	0.000	0.00	0.00	0.000	197
Fin height, mm	0.000	0.00	0.00	0.000	19
Fin thickness, mm	0.000	0.000	0.00	0.000	1.27
Serration, mm	0.000	0.00	0.00	0.000	4.37
Tubes/row	12	12.00	12.00	12	24
Number of rows deep	15	16	12.00	46	12
Length, m	3.650	3.35	3.35	3.650	4.87
Transverse pitch, mm	127	122	122	127	101
Longitudinal pitch, mm	101	127	127	101	101
Streams	0	48.00	36	0	12
Arrangement	inline	inline	inline	inline	inline
Direction of flow		counter	counter		counter
Note: furnace length = 9.76 m, height = 3.96 m, width = 2.44 m, projected area = 142 m^2					

Data for boiler purchases

Industrial boilers can cost millions of dollars, but often, facility personnel purchase a boiler without obtaining crucial data about it. Tables 1–6 show typical data sheets for a steam generator and a water-tube waste-heat boiler. Water-tube data are typically given in two parts: first, the tube's geometric data, and second, its thermal performance. Plant engineers should demand similar data from boiler vendors before they purchase the boiler, and should ensure they have at least most of the information shown here in the tables.

The lack of such thorough data can often lead to confusion in evaluating boiler performance problems or tube failures and can lead to delays when the problem must be fixed immediately. A thermal process consultant tasked with analyzing boiler performance from a heat-transfer point of view must have such data for performing heat-transfer calculations to check whether the original proposal was reasonable or whether the field data correlate with the original design data. Many boiler vendors do not furnish these data as a matter of common practice, and plant engineers often do not realize that they need all this information to evaluate the boiler performance. They may not need the data at the time of the boiler purchase, but they likely will

TABLE 2. DETAILED BOILER PERFORMANCE — AT 100% LOAD					
Surface	Screen	Final SH	Pry SH	Evaporator	Economizer
Gas temp in ±5°C	1,360	1,072	892	778	465
Gas temp out ±5°C	1,072	892	778	465	154
Gas spec. heat, Kcal/kg°C	0.3328	0.3244	0.3163	0.3024	0.2815
Duty, MM Kcal/h	11.78	7.16	4.44	11.60	10.78
U, Kcal/m^{2}h°C	117.81	109.29	104.92	105.23	40.61
Surface area, m^2	105	103	77	322	2395
LMTD, °C	953	639	550	343	111
Gas pressure drop, mm wc	55.22	83.47	54.63	97.00	45.10
Max gas velocity, m/s	51	49	43	33	16
Tube wall temp ±5°C	322	511	386	284	123
Fin tip temp ±5°C	322	511	386	284	136
Weight, kg	2,774	3,298	2,473	8,506	16,071
Fluid temp in, ˚C	222	286	256	222	116
Fluid temp out ±5°C	256	400	313	256	222
Pressure drop, kg/cm^2	0.00	0.50	0.71	0.00	0.93
Fluid velocity, m/s		24.4	26.9		1.7
Fluid heat transfer coeff.	9780	1299	1799	9780	9390
Fouling factor, gas	0.0002	0.0002	0.0002	0.0002	0.0002
Fouling factor, fluid	0.0002	0.0002	0.0002	0.0002	0.0002
Spray, kg/h	3,260				

need it in the future.

I have experienced this problem when plants contact me to solve problems related to underperforming steam systems and lower-than-expected efficiency. The problems include boiler circulation issues, superheater or economizer tube failures, or underperforming steam generators and waste heat boilers. The tube geometry data are either unavailable or are not clear and have to be "made up" in order to evaluate the thermal performance. In some cases, I have also seen drawings that should show tube spacing or the number of streams, but nevertheless is not provided. In other cases, the thermal performance information given is sketchy and without details. This situation is like buying a gadget without an owner's manual and trying to figure out a solution when the gadget fails.

There is a clear need for process and plant engineers to become more familiar with basic boiler calculations, as well as with the data that they should demand to obtain from boiler and HRSG suppliers.

Basic energy-transfer equations

The basic equation for energy transfer in a boiler component is given by Equations (1) and (2).

$$Q = UA\Delta T \qquad (1)$$

ΔT is log mean temperature difference (LMTD; nomenclature on p. 58).

If A is based on the tube inner surface, then U should also be based on tube inner surface. Expressed as a equation, it would be the following:

$$U_i A_i = U_o A_o = Q/\Delta T \qquad (2)$$

If a heat-transfer component receives external radiation from the furnace or cavity, then:

$$Q - Q_r = Q_c + Q_n = UA\Delta T \qquad (3)$$

The energy lost by the hot fluegas stream is absorbed by the colder fluid (steam or water), as shown in the equation below:

$$W_h \Delta h_h = W_c \Delta h_c = Q \qquad (4)$$

This equation neglects heat losses from the casing, which are typically 0.5 to 1.0%. Generally, the higher the boiler duty, the lower the heat loss percentage.

In all sizing or performance calculations, U (the overall heat-transfer coefficient) must be computed. For tubes with extended surfaces, the following equations apply:

$$1/U_o = (A_t/A_i)/h_i + ff_i(A_t/A_i) + ff_o + (A_t/A_w)(d/24K_m)\ln(d/d_i) + 1/h_o\eta \qquad (5)$$

If plain tubes are used, Equation (5) may be simplified to the following Equation (6):

$$1/U_o = d/d_i/h_i + ff_i(d/d_i) + (d/24K_m)\ln(d/d_i) + ff_o + 1/h_o \qquad (6)$$

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FIGURE 4. The photograph shows the exterior of an elevated-drum steam generator for large capacity

The above equations may be used while sizing or evaluating the performance of water-tube boilers, superheaters, economizers and fire-tube boilers.

Which coefficient governs *U*?

The gas-side heat-transfer coefficient governs the performance of boiler components, such as the evaporator, economizer, superheater and gas-fluid heaters. Why is this important to know? When simulating the performance of boiler components or of the boiler as a whole, the effect of gas-side parameters will govern the overall performance, while the steam-water-side parameters will have minimal impact. Therefore, concentrating on gas-side data will enable engineers to perform the analysis for off-design performance rather quickly, instead of having to evaluate both gas- and steam-side heat-transfer coefficients.

In a typical fire tube for example, the gas-side heat-transfer coefficient ranges from 10 to 20 Btu/ft^{2}h°F, while the boiling steam-side or water-side coefficient ranges from 1,500 to 3,000 Btu/ft^{2}h°F, depending on steam pressure and heat flux [*1, 2*]. If d = 2 in., d_i = 1.7 in., $ff_i = ff_o$ = 0.001, and K_m = 25 Btu/ft h°F, then the following calculation can be made:

$1/U_o$ = (2/1.7)/15 + 0.001 × (2/1.7) + 0.001 + 1/1,500 + (2/24/25) ln (2/1.7) = 0.07843 + 0.001176 + 0.001 + 0.000667 + 0.00054 = 0.0818, or U_o = 12.22 or U_i = 12.22 × 2/1.7 = 14.38 Btu/ft^{2}h°F or U_i = 0.958 h_i

Similarly, in a water-tube boiler, steam is boiling inside the tubes and hence, h_i = 1,500–4,000 Btu/ft^{2}h°F, while fluegas flows outside and h_o ranges from 10–20 Btu/ft^{2}h°F. It can be shown from

Equation (6) above that U_o = 14.18 Btu/ft²h°F or U_o = 0.945 h_o.

Now, consider a finned tube evaporator with the following tube geometry: d = 2 in., d_i = 1.77 in., fins/in. = 2, fin height = 0.75 in., fin thickness = 0.049 in. The ratio of outside to inside area is 5.9.

Let us say h_o = 15 Btu/ft²h°F and h_i = 2,500 Btu/ft²h°F.

In this situation, the calculation goes as follows:

$1/U_o$ = 5.9/2,500 + 0.001 × 5.9 + 0.001 + 5.9 × (2/24/25) ln(2/1.77) + 1/(0.73 × 15) = 0.00236 + 0.0059 +.001 + 0.0024 + 0.0913 = 0.109, or U_o = 9.18 Btu/ft²h°F or U_o = 9.18/0.73/15 = 0.84$h_o\eta$ (fin effectiveness is 0.73; Refs. 1 and 2 give details of their evaluation).

For a case in which there is a higher fin density and lower tube-side coefficient (such as a superheater), the ratio will be lower (around 0.75 $h_o\eta$. Hence, for finned tubes, depending on fin geometry, U_o = 0.75 to 0.8 $h_o\eta$. In this case, h_o still governs U_o.

The gas-side heat-transfer coefficient, h_o, consists of convective and non-luminous coefficients. Procedures for estimating convective and non-luminous heat-transfer coefficients in boiler components are given in Ref. 1. Fluid pressure drops inside and outside tubes may also be obtained from Ref. 1. This article does not deal with the estimation of fluegas or steam-water-side pressure drops, only thermal performance.

$$h_o = h_c + h_n \quad \textbf{(7)}$$

The expanded online version of this article (at www.chemengonline.com/performance-prediction-industrial-boilers) describes the procedure for computing heat transfer coefficients for flow inside and outside plain tubes. The expanded version also provides an idea of how the fluegas transport properties can be obtained for a gas mixture. If one can obtain the steam-side heat-transfer coefficient h_i inside a superheater tube, it will help in evaluating tube wall temperatures, as shown in an example also included in the longer online version of this article. In a fire tube boiler, h_i helps to determine the size of the boiler or predict its performance, as it governs U, as shown above.

For gas temperatures below 1,500ºF, neglecting h_n may not lead to significant errors. In fire-tube boilers, since the beam length is tube inner diameter, h_n, will be small and can be neglected. Then $h_i = h_c$.

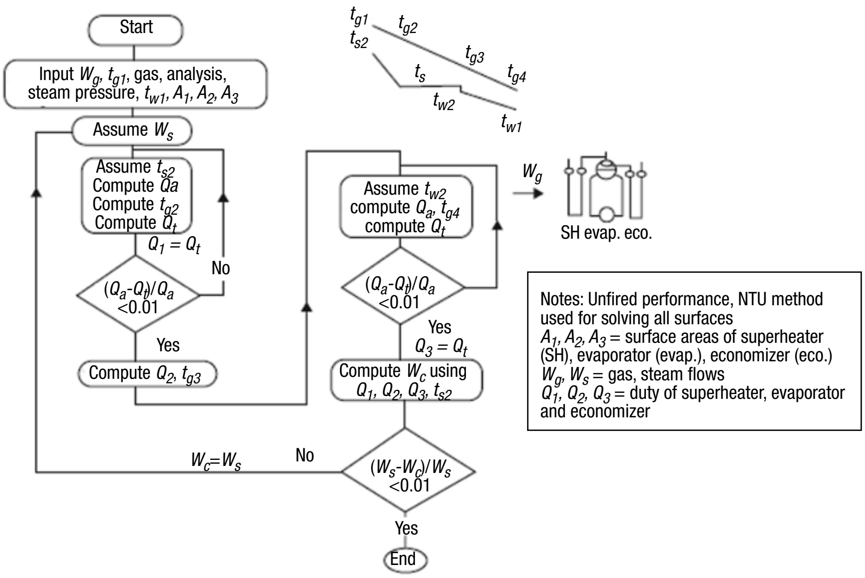

FIGURE 5. Following a logic tree, such as the one shown here for off-design performance of a simple HRSG, can help plant engineers evaluate the effects of various operating conditions

TABLE 3. STEAM GENERATOR PERFORMANCE AT VARIOUS LOADS

Boiler load, %	100	75	50	25	Units
Boiler duty	64.68	48.51	32.34	15.98	Million Kcal/h
Ambient temperature	21.1	21.1	21.1	21.1	°C
Relative humidity	60	60	60	60	%
Excess air	15	15	15	35	%
Fluegas recirculation	0	0	0	0	%
Fuel input (hhv)	77.58	57.89	38.52	19.36	Million Kcal/h
Heat relative rate(HHV)	823,241	614,296	408,750	205,403	Kcal/m³h
Heat relative rate(HHV)	546,978	408,152	271,584	136,476	Kcal/m²h
Steam flow	99,819	74,864	49,909	24,955	kg/h
Steam pressure	42.2	42.2	42.2	42.2	kg/cm²g
Steam temperature	399	399	399	386	±5°C
Feedwater temperature	116	116	116	116	±5°C
Water temp. leaving eco.	222	207	190	183	±5°C
Blowdown, %	1	1	1	1	%
Boiler exit gas temp.	469	417	359	306	±5°C
Eco. exit gas temp.	158	143	132	125	±5°C
Air flow	116,909	87,237	58,047	34,243	kg/h
Fluegas flow	122,934	91,733	61,039	35,746	kg/h
Spray flow	3,260	1,869	492	0	kg/h
Fluegas analysis, losses, efficiency, %					
Dry gas loss	4.62	4.14	3.74	4.18	%
Air moisture loss	0.09	0.08	0.07	0.08	%
Fuel moisture loss	10.55	10.45	10.36	10.31	%
Casing loss	0.50	0.67	1.00	2.00	%
Unacceptable/margin	0.50	0.50	0.50	0.50	%
Efficiency, LHV	92.56	93.03	93.21	91.67	%
Efficiency, HHV	83.75	84.17	84.33	82.94	%
Furnace backpressure	370	201	86	28	mm wc
% vol. CO_2	8.56	8.56	8.56	7.38	
H_20	17.30	17.30	17.30	15.12	
N_2	71.65	71.65	71.65	72.51	
0_2	2.48	2.48	2.48	4.99	
SO_2	0	0	0	0	
fuel flow	6,024	4,494	2,990	1,502	

Two calculation categories

In general, calculations carried out in boiler practice can be divided into

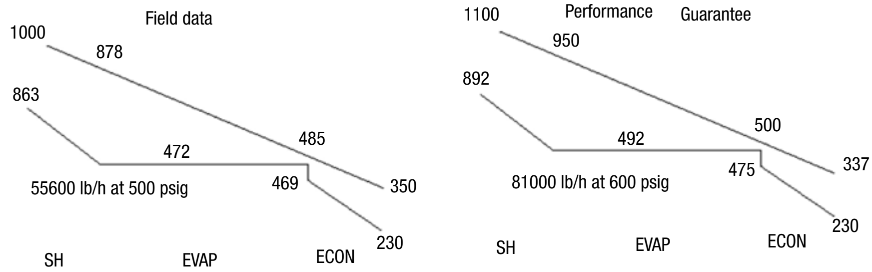

FIGURE 6. HRSG gas-steam temperature profiles in the performance guarantee case (right) and field-data case (left)

TABLE 4. HRSG TUBE GEOMETRY DATA			
	Superheater (SH)	**Evaporator (EVAP)**	**Economizer (ECON)**
Tube OD, in.	1.75	2	2
Tube ID, in.	1.456	1.706	1.706
Fins/in.	2	5	5
Fin height, in.	0.625	0.75	0.75
Fin thickness, in.	0.049	0.049	0.049
Serration, in.	0.172	0.172	0.172
Tubes/row	30	30	30
Number of rows deep	6	20	14
Length, ft	25	25	16
Transverse pitch, in.	4	4	4
Longitudinal pitch, in.	4.5	4	5
Streams	30		10
Direction of flow	counter		counter
Arrangement	inline	inline	staggered

TABLE 5. HRSG GUARANTEE PERFORMANCE						
Exhaust gas flow		500,000	lb/h	Steam pressure	600	psig
Exhaust gas temp.		1,100	±10°F	Steam temp.	892	±10°F
Exhaust gas pressure		14.4	psia	Steam flow	81,094	lb/h
Heat loss		0.5	%	Feed water temp.	230	±10°F
				Blowdown	0	%
Process results						
Surface	SH	Evaporator	Economizer	Units		
Gas temp. in	1,100	950	500	±10°F		
Gas temp. out	950	500	337	±10°F		
Gas specific heat	0.2776	0.2697	0.2591	Btu/lb°F		
Duty	20.8	60.37	21.02	Million Btu/h		
Surface area	8,941	86,379	38,698	ft^2		
Gas press drop	0.22	1.46	3.55	in wc		
Foul factor, gas	0.001	0.001	0.001			
Steam side						
Steam pressure	600	616	623	psig		
Steam flow	81,094	81,094	81,094	lb/h		
Fluid temperature in	492	475	230	±10°F		
Fluid temperature out	892	492	475	±10°F		
Pressure drop	16		7	psi		
Foul factor-fluid	0.001	0.001	0.001			

TABLE 6. FIELD DATA		
Gas temp. in to SH	1,000	±10°F
Gas temp. leaving econ.	350	±10°F
Steam flow	55,600	lb/h
Steam press	500	psig
SH steam temp.	863	±10°F
Feed water temp.	230	±10°F
Water temp leaving econ.	469	±10°F
Drum sat temp.	472	±10°F
Drum pressure	510	psig
Blowdown	0	%
Exhaust gas analysis % vol CO_2 = 3 vol. % , H_2O = 7 vol. %, N_2 = 75 vol. %, O_2 = 15 vol. %		

two categories: design calculations and off-design calculations (Figure 5).

Design, or sizing, calculations. Design calculations are used for sizing a new heat-transfer component, such as superheater, evaporator or economizer, steam generator or a waste heat boiler. Tube size, number of tubes wide and deep, tube and fin geometry and tube spacing are assumed for each component. The hot- and cold-fluid side flows and their inlet and exit temperatures are known from the energy balance. In other words, the energy required to be absorbed by each component is known, and also termed the LMTD (logarithmic mean temperature difference). U values are then computed based on the tube geometry and the surface area A is then obtained. Then, process designers check the gas- and fluid-side pressure drops and tube-wall temperatures to make sure they are reasonable. If not, the exercise is repeated. All boiler suppliers or anyone designing a new heating surface for a given duty would perform this type of calculation.

Off-design, or performance, calculations. In this type of calculation, the tube geometry and surface area of the boiler (or superheater or economizer, as the case may be) are known, as are the fluid flows and inlet temperatures of both hot and cold fluids. It is possible to arrive at the duty, as well as the gas- and fluid-side exit temperatures within a few iterations. Though boiler suppliers have to perform this calculation in part to check the load performance of their components, plant engineers invariably perform this type of calculation when the surface area and tube geometry of the heat-transfer equipment are already available, and the only variables are the hot- and cold-side fluid flows, analysis, fluid temperatures and steam pressure.

While there can be only a single design calculation, there can be numerous off-design calculations. Although boilers are designed for one set of parameters, any given boiler will likely operate under variable loads and parameters. Becoming familiar with off-design calculations will help plant engineers evaluate "what if" scenarios on boiler components and enable them to notify plant personnel of potential problems resulting from changing process parameters.

Off-design calculation methods

There are two approaches to performing off-design calculations for equipment, such as a superheater or economizer or a fluid heater. Note that evaporator calculations are simpler due to the fact that the boiling water temperature is constant throughout the exchanger. The hot- and cold-side fluegas flows and inlet temperature and analysis are known. The objective is to obtain the duty

TABLE 8. EFFECTIVENESS FACTORS FOR EXCHANGERS	
Parallel-flow, single-pass	$\varepsilon = \frac{1-\exp[-NTU\times(1+C)]}{1+C}$
Counter-flow, single-pass	$\varepsilon = \frac{1-\exp[-NTU\times(1-C)]}{1-C\exp[-NTU\times(1-C)]}$
Shell-and-tube (one shell pass; two, four, six and so on, tube passes)	$\varepsilon_1 = 2\left[1+C+\frac{1+\exp[-NTU\times(1+C^2)^{1/2}]}{1-\exp[-NTU\times(1+C^2)^{1/2}]}\times(1+C^2)^{1/2}\right]^{-1}$
Shell-and-tube (n shell pass; 2n, 4n, 6n, and so on, tube passes)	$\varepsilon_n = \left[\left(\frac{1-\varepsilon_1 C}{1-\varepsilon_1}\right)^n - 1\right]\left[\left(\frac{1-\varepsilon_1 C}{1-\varepsilon_1}\right)^n - C\right]^{-1}$
Cross-flow, both streams unmixed	$\varepsilon = \frac{1-\exp[-NTU\times(1-C)]}{1-C\exp[-NTU\times(1-C)]}$
Cross-flow, both streams mixed	$\varepsilon = NTU\left[\frac{NTU}{1-\exp(-NTU)}+\frac{NTU\times C}{1-\exp(-NTU\times C)}-1\right]^{-1}$
Cross-flow, streams C_{min} unmixed	$\varepsilon = \{1-\exp[-C[1-\exp(-NTU)]]\}/C$
Cross-flow, streams C_{max} unmixed	$\varepsilon = 1-\exp\{-1/C[1-\exp(-NTU\times C)]\}$

and the exit hot- and cold-side fluid temperatures. These calculations are applicable for single-phase fluids only and no external radiation is assumed to be present.

Conventional method. The procedure for the conventional method is as follows:

- Assume the exit temperatures of the hot gas stream (T_2, T_1, t_1) are known
- Compute the assumed duty $Q_a = W_h Cp_h (T_1 - T_2)$ (W_h, W_c are known)
- Compute the exit temperature of the cold fluid t_2 using $t_2 = t_1 + Q_a/W_c/Cp_c$
- Compute the LMTD, since all four temperatures are known
- Compute U using equations discussed in the online section of this article and in Refs. 1 and 2. Compute the transferred duty $Q_t = UA\Delta T$
- If both Q_a and Q_t are within a small range (~0.5%), then we may stop the iteration. If not, change T_2 in Step 1 and repeat the protocol until the difference is 0.2% or less.

Quick convergence logic may be used to speed up the calculations. Each time the gas or steam/water temperature is corrected, the corresponding gas and fluid properties, and also the heat-transfer coefficients, will change. A computer program is ideal for such an exercise, because the manual calculations become tedious. However, engineers should know how to do these calculations manually in order to develop a computer program. Ref. 1 also contains numerous manually calculated examples for various types of boiler equipment.

NTU method of performance evaluation. The Number of Transfer Units (NTU) method is the most widely used method in the chemical process industries (CPI), as it "directly" solves for the duty, although a few iterations will help to improve the accuracy. U is dependent on the average gas temperature or film temperature and on the fluid properties, which impact the heat-transfer coefficients with changing temperatures. A new equipment design also can also be evaluated by the NTU method. Simply change the tube geometry of the heat exchanger to match the desired performance, and then freeze the design. Following that, the off-design performance is evaluated for several cases. Hence, the NTU method can be used for a design calculation or an off-design calculation. Effectiveness, ε, is the most important factor in these calculations and once it is arrived at, the duty of the exchanger can be obtained.

Table 8 shows the effectiveness factor for various arrangements. It is sufficient if the fluid flows and the hot and cold fluid inlet temperatures are known. In that case, the following equations apply.

$$Q = \varepsilon C_{min} (T_1 - t_1) \quad \textbf{(8)}$$

$$C_{min} = (WCp)_{min} \quad \textbf{(9)}$$

$$Cmax = (WCp)_{max} \quad \textbf{(10)}$$

$$C = C_{min}/C_{max} \quad \textbf{(11)}$$

$$NTU = UA/(WCp)_{min} \quad \textbf{(12)}$$

These terms may be used in the equations shown in Table 8 to estimate ε for the exchanger configuration in question. Once ε is obtained, the duty may be obtained. Thereafter, the exit fluid temperatures are obtained. Using multiple iterations will improve the accuracy of the fluid properties and specific heats. Examples shown in the online version of this article illustrate this procedure for evaluating off-design performance of superheater, economizer, fluid heater, such as glycol heated by exhaust gases from a gas turbine.

Evaporator performance

Fire-tube boiler or water-tube evaporator performance may be obtained in a far easier manner compared to superheaters or economizers. Since the cold-side fluid temperature is constant at saturation temperature, this evaluation is rather simple. T_1 and T_2 refer to hot gas inlet and exit temperatures, respectively, and t_s is the saturation temperature. Neglecting casing heat losses, the following equation can be written:

$$W_g Cp_g (T_1 - T_2) = Q = UA\Delta T = UA [(T_1 - t_s) - (T_2 - t_s)] / \ln[(T_1 - t_s) / (T_2 - t_s)] \quad \textbf{(13)}$$

Simplifying Equation (13) yields:

$$\ln [(T_1 - t_s) / (T_2 - t_s)] = UA / (W_g Cp_g) \quad \textbf{(14)}$$

This equation may be used either for designing an evaporator or for checking its off-design performance.

If T_1 and t_s are known, Equation (14) may be used to obtain T_2, and from that, duty (Q), as well as the steam generation in the evaporator, may be estimated, if the enthalpy of the feed water entering the evaporator and the enthalpy of saturated steam at operating pressure are both known. The value for T_2 obtained from the previous calculations may be compared with the field data to check whether the evaporator is performing well. This equation may also be used to arrive at the surface area A, if T_1, T_2, t_s and tube geometry and gas flow are known. The important Equation (14) also allows users to see what happens to the boiler duty with steam pressure changes.

Challenging the HRSG vendor

Savvy process engineers familiar with such calculations can use the data provided by the HRSG supplier, along with field data, to evaluate whether or not the boiler supplier has overstated claims regarding steam generation and temperature profiles. Using the data provided by the HRSG supplier (Table 5) we see that the duty shown by the supplier for the evaporator is 60.37 million Btu/h, while our estimate (using the field data at a lower load) for the same guarantee case is only 58.7 million Btu/h.

Equation (14) comes in handy to see what is really happening here. Our estimate of UA for the evaporator from above is 4.92 × 86,379 = 424,985. Now using vendor data, we see from Equation (14) that: $\ln[(950–492) / (500–492)] = UA/(500{,}000 \times 0.27 \times 0.995) = 4.0474$ from which UA_{vendor} = 543,670 Btu/h°F], or a 28% higher value of UA has been used by a vendor for the same cross-section, tube spacing, surface area. This means that the supplier has overestimated the U value by 28% and submitted guaranteed results.

Plant engineers can perform such analyses for each section once they become familiar with these calculations and challenge the boiler supplier if performance is significantly different from predicted. However, in order to do this as mentioned earlier, good field data must be available. They can measure the gas temperatures at the evaporator inlet and exit, and prove that the performance is close to what is predicted by the vendor.

For example, in the actual operation case, if the steam temperature of 863°F, gas temperature at exit of evaporator and economizer of 485°F and 350°F and steam/water flow of 55,600 lb/h are accurately measured and shown to be close, then they have established their energy balance by calculation, as well as by measurements, and the HRSG vendor will have a difficult time justifying the design and guarantees.

Plant owners spend millions of dollars on HRSGs. They should also ensure the HRSG is well-instrumented with numerous gas and water/steam measurement points. Presently, many HRSG vendors provide a tapping point at the HRSG exit alone and plant owners do not generally think much about HRSG instrumentation at multiple locations of the HRSG. This is not a good practice. There should be multiple tapping points ahead and after each heating surface (particularly if the cross-section of HRSG is large), well-calibrated instruments and frequent checks on these readings by qualified instrumentation engineers to ensure the thermocouples are not plugged or damaged. Armed with such field data, it will be easier for the plant to simulate the HRSG performance at any operating point and extrapolate the results to guarantee conditions, or vice versa, and challenge the HRSG supplier if large deviations in steam generation or gas/steam temperatures are observed (Figure 6). Such independent analysis capability goes a long way toward ensuring effective HRSG operation and thorough examination of proposals from HRSG suppliers who do not "wing it" when it comes to stating thermal performance just to sell the equipment.

Concluding remarks

The examples shown in the extended online-only version of this article illustrate the point that a simplified approach could be used to evaluate the thermal performance of boilers and their components, such as superheater, economizer fire tube or water tube evaporator or fluid heaters. *U* or (*UA*) could be obtained for the field data case and extrapolated for another set of operating conditions to determine the thermal performance. It is important that plant engineers obtain as much tube geometry data and thermal performance information from boiler suppliers before ordering the boilers, which will help them in their calculations at a later date. Using these, they can evaluate the performance at off-design conditions.

Ref. 1 provides more information on calculation procedures considering direct radiation, non-luminous radiation and hence more accurate procedures can be set up by plant engineers for each boiler in their plant, including steam generators. They can use the results to monitor the performance of various components and large deviations from "predicted" values can be taken up for more detailed analysis.

Though these procedures may not be as accurate as predicted by a complete boiler performance program, these calculations give an idea how process engineers can use field data to predict performance at any other operating point. The calculations should be backed up by proven instrumentation, which will make their performance predictions more reliable. Knowledge of these procedures will help plant engineers to become more informed and challenge boiler vendors in case they offer "inadequate" or inaccurate process thermal performance data while selling their boilers. Computer code can be developed by process engineers to model each boiler performance in their plant, which will help them to assess whether or not changes in the operating conditions are likely to cause unfavorable conditions in their boiler equipment. ■

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Table 7: EXHAUST GAS PROPERTIES				
temp,F	Cp	μ	k	Fg
200	0.253	0.0517	0.0182	0.1119
400	0.2585	0.0612	0.0218	0.1205
600	0.2645	0.0703	0.0253	0.1284
800	0.2706	0.0789	0.0287	0.1356
1000	0.2769	0.087	0.0321	0.1428
1200	0.2831	0.0948	0.0355	0.1497

ONLINE EXTRAS

HRSG performance calculations

Often, heat-recovery steam generators (HRSGs) are designed for a particular set of gas inlet conditions. However, once installed, due to various plant limitations, such as gas turbine load, steam or feed water parameters, the HRSG may not operate at the designed gas-inlet conditions. Then how does one know that the HRSG will perform as guaranteed once the appropriate gas inlet parameters are provided? This example shows what can be done.

HRSG performance calculation Example 1: An unfired HRSG is designed with the parameters shown in Tables 4 and 5, and the supplier has guaranteed performance as shown at 500,000 lb/h exhaust gas flow and at 1,100°F inlet gas temperature with a steam flow of 81,000 lb/h of 600 psig steam at 892°F. In operation however, the HRSG generates only 55,600 lb/h steam at 500 psig at 863°F. Inlet and exit gas temperatures are 1,000°F and 350°F, as shown in Table 6. Plant engineers want to know if this performance is acceptable. The boiler supplier says that, due to inadequate exhaust gas flow and temperature, the HRSG is making less steam than guaranteed, and that the vendor's design is acceptable. Is the vendor correct?

Solution: Tables 4, 5 and 6 show the information given by the HRSG supplier and the field data. This is a problem commonly faced by plant engineers. The newly purchased HRSG operates at some gas/steam parameters that are not close to the design parameters. How can plant engineers determine if the HRSG was sized properly and if it will meet guaranteed performance after a few years, when gas inlet conditions for the guarantee case are provided? Suppliers' warranties typically last for one year and any performance problems must be corrected by the vendor within that period. However, now since the plant is unable to provide the design gas inlet conditions within a year, the plant engineers are in a difficult position — that is, they are not sure if the HRSG has sufficient surface or not. However, using the simplified approach, the plant engineers can get a good estimate of how the HRSG will perform in the guarantee case or whether it will meet or not meet the guaranteed steam production.

Let us first establish the complete field data. It will help if we have accurately measured data, such as the water temperature entering and leaving the economizer, the drum temperature, the gas temperature at inlet and exit of the HRSG, the water and steam flows and steam temperatures. Using these data, it is possible for a process engineer to get a good idea of what the HRSG will do when the exhaust gas inlet is at "design" (guarantee case) conditions (namely 1,100°F and flow 500,000 lb/h). Presently, the gas flow is much lower. Exhaust gas-flow measurement is generally not accurate and hence it is obtained by energy balance based on energy absorbed by steam.

The data shown in Table 6 from the field should be used to generate the complete HRSG gas/steam temperature profiles. Since exhaust gas, steam and water temperatures and water flow are accurately mea-

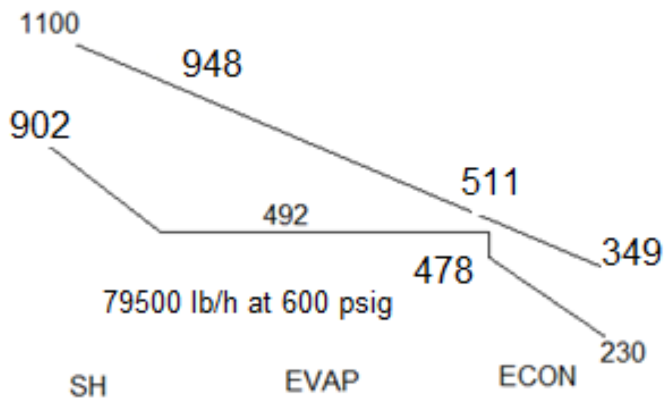


FIGURE 7. This diagram shows the expected boiler performance, based on the simulation

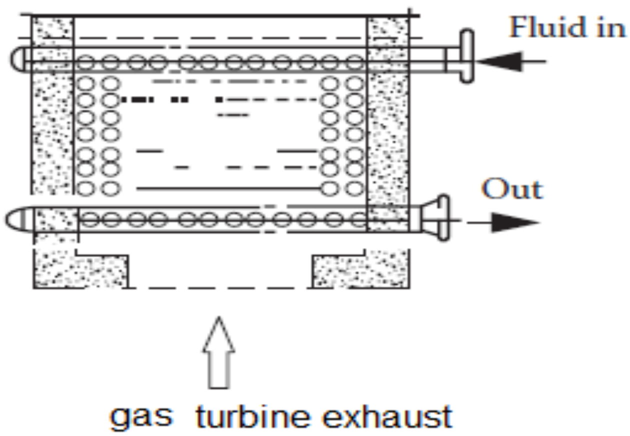


FIGURE 8. This diagram shows the arrangement of the fluid heater in the steam system

sured, let us use these to obtain the exhaust gas flow.

From steam tables, we can obtain the following: enthalpy of final steam at 863°F, 515 psia is 1,446.2 Btu/lb. Enthalpy of feed water at say 550 psia, 230°F is 199.5 Btu/lb. Energy absorbed by steam (no blowdown used to simplify the calculations) = 55,600 × (1,446.2 – 199.5) = 69.32 million Btu/h.

Heat loss on the gas side is taken as 0.5%. Exhaust gas flow = 69.32 × 10^6/ [0.995 × 0.2667 × (1,000 – 350)] = 401,880 lb/h (0.2667 is the gas specific heat at the average gas temperature of 675°F).

Let us do a similar energy balance at the superheater to determine the gas temperature leaving the superheater. Energy to steam = 55,600 × (1,446.2 – 1,204.8) = 13.42 million Btu/h (saturated steam enthalpy being 1,204.8 Btu/lb). At the average gas temperature of say 940°F, C_p = 0.275. Hence, gas temperature leaving superheater = 10,00 – 13.42 × 10^6 / (401,882 × 0.995 × 0.275) = 878°F.

Energy absorbed by the economizer = 55,600 × (451.8 – 199.5) = 14.03 million Btu/h

Gas temperature entering economizer = 350 + 14.03 × 10^6 / (401,882 × 0.995 × 0.2591) = 485°F.

Evaporator duty by difference = 69.32 – 14.03-13.42 = 41.87 million Btu/h.

Let us compute the U values for each section from field data, as now we can get LMTD for each section and we also know the surface area and duty of each section.

LMTD SH = [(1,000–863) – (878–472)] / ln[(1,000–863)/(878–472)] = 248°F.

LMTD evaporator = [(878–485) / ln [(878–472) / (485–472)] = 115°F

LMTD economizer = [(120–16) / ln(120/16)] = 52°F

U_1 = 13.42 × 106 / (8,941 × 248) = 6.06 Btu/ft²h°F (superheater)

U_2 = 41.87 × 10^6 / (86,379 × 115) = 4.21 Btu/ft²h°F (evaporator)

U_3 = 14.03 × 10^6 / (38,698 × 52) = 6.97 Btu/ft²h°F (economizer)

Using these computed values of U from field data, let us verify the steam generation in the guarantee case using the NTU method and the flow logic for the off-design performance calculations shown in Figure 6. We need to confirm if 81,000 lb/h at 600 psig and 892°F as guaranteed by the HRSG supplier is, in fact, feasible. First, let us correct U_1, U_2, U_3 for the guarantee case as follows:

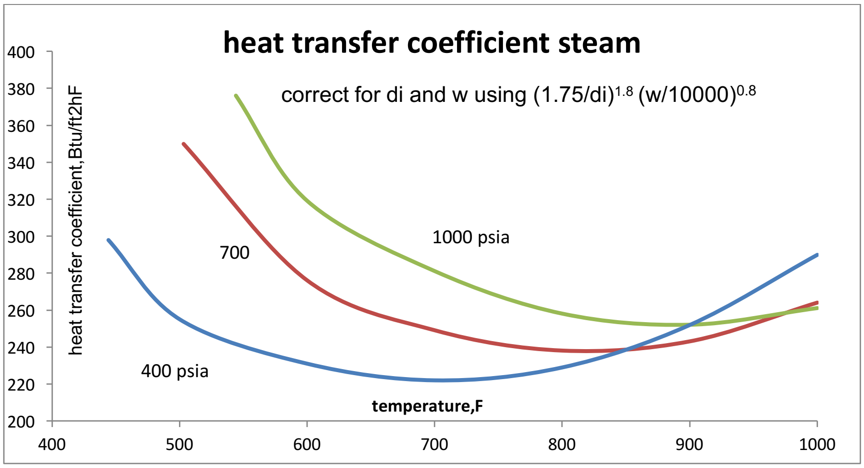


FIGURE 10. The graph shows the heat-transfer coefficient of steam as a function of pressure and temperature

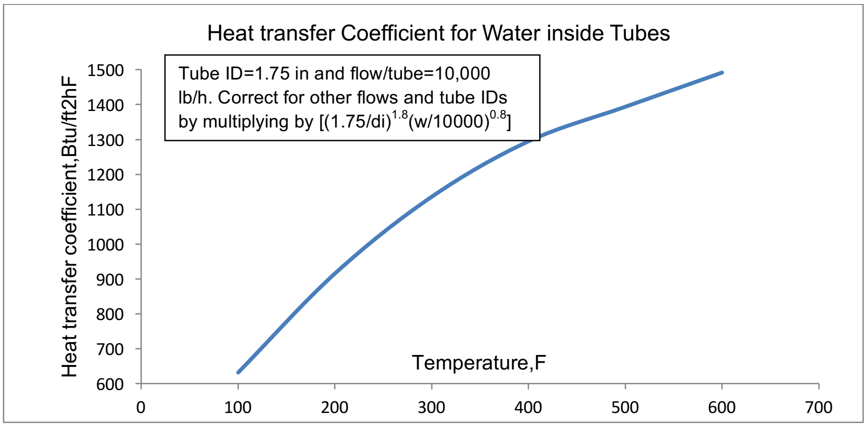


FIGURE 11. Heat transfer coefficient for water flowing inside tubes

For the superheater:

$$(UA)_p = (UA)_d (Wg_p/Wg_d)^{0.65} (Fg_p/Fg_d) (Ws_p/ws_d)^{0.15} \quad (15)$$

The steam flow term may be deleted for evaporator and economizer $(UA)_p$ calculations as the effect of steam flow (evaporator) or water flow (economizer) has minimal impact on U. The correction factor F_g for flue-gas properties is discussed in Appendix 2 of this online section.

Superheater

From Refs. 1, 2 and 3, the following can be observed:

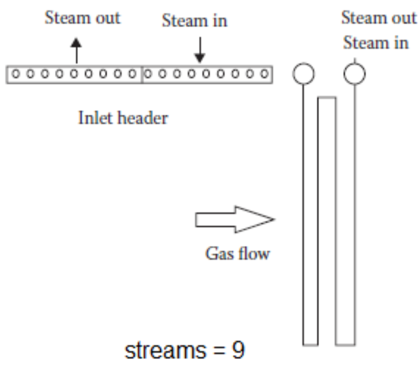


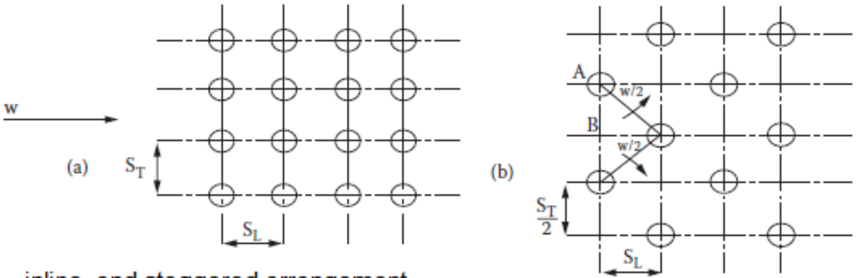
FIGURE 12. Superheater has 18 tubes/row and nine streams

U_{1c} = 6.06 × (500,000 / 401,882)$^{0.65}$ × (0.1438 / 0.1407) × (81,000 / 55,600)$^{0.15}$ = 7.55 Btu/ft²h°F. (0.1438 and 0.1407 are F_g factors based on gas properties shown in Table 7. F_g of 0.1438 is at the average gas temperature in superheater of 1,025°F in the guaran-

Table B1:Fh factor

F_h for Inline and Staggered Arrangements

S_L/d		1.25	1.5	2	3	1.25	1.5	2	3
S_T/d	Re	Inline Bank				Staggered Bank			
1.25	2,000	1.06	1.06	1.07	1	1.21	1.16	1.06	0.96
1.25	8,000	1.04	1.05	1.03	0.98	1.11	0.99	0.92	0.95
1.25	20,000	1	1	1	0.95	1.04	1.02	0.98	0.94
1.5	2,000	0.95	0.95	1.03	1.03	1.17	1.15	1.08	1.02
1.5	8,000	0.96	0.96	1.01	1.01	1.1	1.06	1.00	0.96
1.5	20,000	0.95	0.95	1.0	0.98	1.04	1.02	0.98	0.94
2	2,000	0.73	0.73	0.98	1.08	1.22	1.18	1.12	1.08
2	8,000	0.83	0.83	1	1.02	1.12	1.1	1.04	1.02
2	20,000	0.90	1	1	1	1.09	1.07	1.01	0.97
3	2,000	0.66	0.66	0.95	1	1.26	1.26	1.16	1.13
3	8,000	0.81	0.81	1.02	1.02	1.16	1.15	1.11	1.06
3	20,000	0.91	0.91	1.01	1	1.14	1.13	1.1	1.02



inline and staggered arrangement

Table C1: Gas analysis and properties

How are the gas properties C_p, μ, and k estimated for a gaseous mixture? Determine C_p, μ, and k for a gas mixture having the following analysis at 1650°F and 14.7 psia.

Gas	Vol%	C_p	μ	k	MW
N_2	80	0.286	0.108	0.030	28
O_2	12	0.270	0.125	0.043	32
SO_2	8	0.210	0.105	0.040	64

tee case, while 0.1407 is F_g at the average gas temperature of 939°F in the field data case).

Cp_s = (1,458.28-1203.3)/(892-492) = 0.6375. Cp_g = 0.275

C_{min} = 81,000 × 0.6375 = 51637; C_{max} = 500,000 × 0.995 × 0.275 = 136,812

C = (51,637 / 136,812) = 0.3774. NTU = 7.55 × 8941 / 51,637 = 1.3081 (8,941 is the surface area of the superheater)

ε = [1-exp{–1.3081 × (1–0.3774)}]/ [1-0.3774x exp{–1.3081 × (1–0.3774)}] = 0.6685

Q_1 = 0.6685 × 51,637 × (1,100-492) = 20.99 million Btu/h

Gas temperature leaving superheater = 1,100 – 20.99 × 10^6 / (500,000 × 0.995 × 0.275) = 947°F

Steam temperature leaving the superheater = 492 + 20.99 × 10^6 / (81,000 × 0.6375) = 898°F

Enthalpy of superheated steam = 1,461.58 Btu/lb

Evaporator

U_{2c} = 4.21 × (500,000 / 401,882)$^{0.65}$ × (0.1329/0.131) = 4.92 (from Equation (14))

ln [(947-492)/(T_2–492)] = 4.92 x 86,379 / (500,000 × 0.995 × 0.27) or exit gas temperature from the evaporator T_2 = 511°F

Duty of evaporator = 500,000 × 0.995 × (948 – 511) × 0.27 = 58.57 MM Btu/h

Economizer

U_{3c} = 6.97 × (500,000/401,882) 0.65 = 8.03. F_g correction is not applied since the average gas temperature in both the guarantee case and the field data case are nearly same.

Specific heat gas = 0.259 and that of water = 1.057 (from water enthalpy data)

C_{min} = 81,000 × 1.057 = 85,617. C_{max} = 500,000 × 0.995 × 0.259 = 128,825

C = 0.6646. NTU = 8.03 × 38,698 / 85,617 = 3.629

∈ = [1-exp(–3.629 × 0.3354)]/ [1–0.6646 × exp{–3.629 × 0.3354] = 0.8766

Q_3 = 0.8766 × 85,617 × (511–230) = 21.08 million Btu/h

Water temperature leaving economizer = 230 + 21,080,000 / 85,617 = 476°F

Exit gas temp = 511 – 21.08 × 10^6/ (500,000 × 0.995 × 0.259) = 347°F

Total energy absorbed = 20.99 + 58.57 + 21.08 = 100.64 million Btu/h

From transferred duty, steam flow = 100.64 × 10^6/(1461.58 – 199.7) = 79,750 lb/h

Second iteration: superheater

Using the same Cp_s and Cp_g, C_{min} = 79,750 × 0.6375 = 50,841 and C_{max} = 500,000 × 0.995 × 0.275 = 136,812. C = 0.3716. NTU = 7.55 x 8,941 / 50,841 = 1.3277

∈ = [1–exp{–1.3277 × (1–0.3716)}] / [1–0.3718 x exp{–1.3277 × (1–0.3716)}] = 0.5658/0.8387= 0.6746

Q_1 = 0.6746 × 50,841 × (1,100-492) = 20.85 MM Btu/h. t_{s2} = 492 + 20.85 × 10^6 / 50,841 = 902°F

T_{g2} = 1,100 – 20.85 × 10^6 / 136,812 = 948°F

Second iteration: evaporator

Using the same U_{2c}, ln[(948–492)/ (T_2 – 492)] = 4.92 × 86,379/(500,000 × 0.995 × 0.27) or exit gas temperature from evaporator = 511˚F. Q_2 = 500,000 × 0.995 × 0.27 x (948–511) = 58.7 million Btu/h

Second iteration: economizer

Using the same specific heats for water and fluegas and U_{3c}, C_{min} = 79,750 × 1.057 = 84,296

C_{max} = 500,000 × 0.995 × 0.259 = 128,825.

C = 0.6543 NTU= 8.03 × 38,698 / 84,296 = 3.6863

ε = [1−exp{−3.6863 × (1 − 0.6543)}] / [1−0.6543 × exp{−3.6863 × (1 − 0.6543)}] = 0.8818

Q_3 = 0.8818 × 84296 × (511 − 230) = 20.89 million Btu/h

t_{w2} = 230 + 20.89 × 10^6 / 84296 = 478°F, T_{g2} = 511 − 20.89 × 10^6 / 128,825 = 349°F

Total energy transferred = 20.99 + 58.7 + 20.89 = 100.58 million Btu/h

Corrected steam flow = 100.58 × 10^6 / (1,463.78 − 199.7) = 79,560 lb/h

Let us go with 79,560 lb/h as the expected steam from this HRSG in guarantee case. Since the estimated value is far lower than that guaranteed, the plant has a strong case to inform the HRSG supplier that there is a need to verify the design and correct it. The exit gas temperature guaranteed by them is also on the low side by a significant margin (349°F versus 337°F). The energy absorbed 102 million Btu/h as guaranteed by them also cannot be met with the existing surface areas. The plant can show that the duty of the HRSG in the guaranteed case is only about 100.5 million Btu/h. The HRSG supplier will argue about measurement errors, calibration of instruments and so on. But there is a strong case that the HRSG will generate only about 79,500 lb/h steam at 900°F based on how it is presently performing. Plant engineers should familiarize themselves with such calculation processes. An excel work sheet or VBA coded excel can help in more accurate results instead of manual calculations.

Superheater Example 2

A finned-tube counterflow superheater in a petroleum refinery is experiencing high tube-wall temperatures as measured at the steam outlet end. See data in Table 9. The operator is thinking of making it a parallel flow unit to lower the tube temperatures. What will be the performance and tube wall temperature if it is made a parallel flow unit? How much should the steam flow be reduced to get the same steam temperature as before for process?

Fluegas analysis: vol.% CO_2 = 8 vol.%, H_2O = 18 vol.% ,N_2 = 72 vol.%, O_2 = 3 vol.%.

The plant is experiencing high tube-wall temperatures and failures in its superheater. and wants to understand why this is happening. It wants to know if parallel flow design will help as a temporary measure and what will be its performance? If the same steam temperature of about 880°F is required in parallel flow arrangement for process reasons, can they reduce the steam flow and by how much? What will be the maximum tube wall temperature in both cases?

Solution: Let us first understand why they have a problem. High finned superheaters increase the heat flux inside the tubes as discussed in several articles (Refs. 1 and 4) and hence should be designed with caution.

The ratio of external to internal

TABLE 9: SUPERHEATER OPERATING DATA

Arrangement	Counter flow	Parallel flow	Parallel flow
Case	Operating	Proposed	Lower steam flow
Gas flow, lb/h	176,000	176,000	176,000
Gas inlet temp, °F	1,472	1,472	1,472
Gas exit temp, °F	839	927	977
Steam inlet temp, °F	508	508	508
Steam flow, lb/h	132,000	132,000	105,000
Steam press exit, psig	700	700	700
Steam exit temp, °F	894	833	890
Maximum tube wall temp, °F	1,123	890	933
Surface area-total, ft^2	10,195		
Tube OD,ID, tube length	2 × 1.75 × 10.2		
Fins/in, ht, thick	4 × 0.75 ×.075 × 0.157		
Rows wide × deep × streams	24 × 8 × 24		

TABLE 10:THERMAL FLUID HEATER QUOTES

	Vendor 1	Vendor 2
Turbine exhaust flow,lb/h	150,000	150,000
Gas temperature in, F	950	950
Gas temperature out, F	551	551
Duty, MM Btu/h	15.94	15.94
Gas pr drop, in wc	3.2	2.2
Paramtherm1 flow, lb/h	80,000	80,000
Inlet temperature, F	250	250
Exit temperature, F	547	547
Pressure drop, psi	9	12
Tube size, OD x ID	2	2
Fins/in. × height × thickness	5 × 0.75 × 0.075	2 × 0.75 × 0.075
Tubes/row	15	15
No deep	10	14
Length, ft	8.5	8.5
Trans and long pitch, in.	4.5 × 4.5	4.5 × 4.5
Surface area, ft^2	7,740	4,895
Arrangement	Staggered	Staggered
Streams	5	5

TABLE 11: RESULTS OF CALCULATIONS FOR THERMAL FLUID HEATER

	Vendor 1	Vendor 2
Average U, Btu/ft^{2}h°F	5.9	9.33
Fluid heat transfer coefficient @ 400°F	233	233
fluid heat transfer coefficient @550°F	387	387
F_g at average gas temperature of 750°F	0.134	
F_g at maximum gas temperature of 950°F	0.141	
Maximum U, Btu/ft^{2}h°F	6.21	9.82
Max heat flux inside tubes, Btu/ft^{2}h	32,550	23,257
Film temp rise, °F	84	60
Max film temperature, °F	634	610

TABLE 12: DATA FOR FIRE TUBE BOILER			
Data	**Design**	**Case 2**	**Case 3**
% plugged tubes	No	No	15%
Air flow, lb/h	70,000	?	70,000
Gas inlet temperature, F	1,200	1,000	1,200
Gas exit temperature, F	615	525	622
Duty, MM Btu/h	10.7	4.93	?
Feed water temperature, F	230	230	230
Steam pressure, psia	615	415	615
Sat temperature, F	489	448	489
Steam flow,lb/h	10,700	4,900	?
Heat loss, %	1	1	1
Gas pressure drop, in wc	3.4	1.0	4.4
Tubed OD/ID, in	2/1.7	2/1.7	
Number of tubes	425	425	361
Length, ft	16	16	

surface areas = 10,195 × 12/(3.14 × 1.75 × 24 × 8 × 10.2) = 11.37

Let us compute U_o using the present set of data. The duty is 132,000 × ($h_o - h_i$).

From steam tables, h_o = enthalpy of steam at 894°F and 715 psia is 1,455 Btu/lb. At inlet, saturated steam enthalpy at 730 psia is 1,201.2 Btu/lb and saturation temperature is 508°F. Duty = 132,000 × (1,455–1,201.2) = 33.5 million Btu/h.

The average gas specific heat at 1155°F is 0.3035 Btu/lbF. Assume heat loss is 1%.

Then the exit gas temperature = 1472-33.5 × 10^6 /(176,000 × 0.99 × 0.3035) = 839°F

LMTD = [(1,472 – 894) – (839–508)] / ln [(1,472 – 894) / (839 – 508)] = 443°F

U_o = 33.5 × 10^6 / 10,195 / 443 = 7.42 Btu/ft²h°F.

This is the average heat transfer coefficient at the average gas temperature. The maximum U_o will be that at 1,472°F. Using the factor F_g = $Cp^{0.33}k^{0.67}/\mu^{0.32}$, it can be shown using gas properties at 1,472°F and 1,161°F that F_g at 1,472°F = 0.168, and that at 1,161°F = 0.156.

Hence maximum U_o = 0.168 × 7.42 / 0.156 = 7.99 Btu/ft²h°F. The maximum heat flux inside the tubes is = 7.99 × 11.37 × (1,472–894) = 52,509 Btu/ft²h.

The tube-side heat-transfer coefficient can be shown to be 275 Btu/ft²h°F at 715 psia and 894°F from Figure 10. Flow per tube = 132,000 / 24 = 5,500 lb/h (One can appreciate the importance of streams here as discussed in Appendix 1). From Figure 10, h_i = 243 × $(5,500/3,300)^{0.8}$ × $(1.5/1.75)^{1.8}$ = 277 Btu/ft²h°F

The steam film temperature drop = 52,509 / 277 = 190°F. If a fouling factor of 0.0005 is used on steam side, then inner tube-wall temperature will be 894 + 190 + 0.0005 × 52,509 = 1,110°F. Wall resistance drop = 0.00052 × 52,509 = 26°F. Hence, the maximum mid-wall temperature is 1,110 + 13 = 1,123°F.

This is rather high, as thickness required by ASME code for T22 material exceeds 0.22 in for a design pressure of 800 psig, while only 0.125 in. has been used. The measured tube wall temperature also is around 1,120°F. Hence the design was ill conceived in the first place. For superheaters, a small amount of finning only should be used, while in evaporators and economizers, we can use higher ratio of external to internal surface area as explained in Refs. 1 and 4.

Parallel flow superheater

Let us use the NTU method to determine the performance if the superheater arrangement were made parallel flow with the same gas and steam flows as operating case. From the operating case earlier, the average gas side specific heat is 0.3035 and steam side specific heat is 0.657. F_g can be shown to be 0.156 and 0.168 at 1,155°F and at 1,472°F, respectively.

C_{min} = 176,000 × 0.99 × 0.3035 = 52,882. C_{max}=132,000 × 0.657 = 86724. C = 52,882 / 86,724 = 0.61

Use the same U_o as before for the first iteration. Then NTU = 7.42 × 10,195 / 52,882 = 1.43

ε = 1–exp[–1.43 × (1 + 0.61)]/(1+0.61) = 0.559

Hence, duty Q = 0.559 × 52, 882 × (1,472 – 508) = 28.5 million Btu/h

Exit steam temperature = 508 + 28.5 × 10^6 / 132,000 / 0.657 = 837°F.

Let us do another round of iteration to get more accurate results.

Exit gas temperature = 1,472–28.5 × 10^6 / (176,000 × 0.99 × 0.3035) = 933°F

Average gas temperature is 1,203°F and average steam temperature is 673°F. From the enthalpy of steam, Cp_s = (1,423.7–1,201.2)/(837–508) = 0.676 and Cp_g = 0.3051 from Table C2 in Appendix 3.

Then C_{min} = 176,000 × 0.99 × 0.3051 = 53,643 and C_{max} = 132,000 × 0.676 = 89,232

C = 53,643 / 89232 = 0.601. Average U = 7.42 × (0.1576/0.1558) = 7.51 Btu/ft²h°F.

NTU = 7.51 × 10,195 / 53,643 = 1.427

ε = 1–exp[1.4 43 × (1 + 0.61)] / (1 + 0.61) = 0.559

Hence duty Q = 0.559 × 52,882 × (1,472–508) = 28.5 million Btu/h

Exit steam temperature 508 + 28.5 × 10^6/132,000/0.657 = 837°F.

Let us do another round of iteration to get more accurate results:

Exit gas temperature = 1,472 – 28.5 × 10^6 / (176,000 × 0.99 × 0.3035) = 933°F

Average gas temperature is 1,203°F and average steam temp is 673°F.

From enthalpy of steam, Cp_s = (1,423.7 – 1,201.2) / (837 – 508) = 0.676 and Cp_g = 0.3051 from Table C2 in Appendix 3.

Then:

C_{min} = 176,000 × 0.99 × 0.3051 = 53,643 and C_{max} = 132,000 × 0.676 = 89,232

C = 53,643/89,232 = 0.601

Average U = 7.42 × (0.1576 / 0.1558) = 7.51 Btu/ft²h°F

NTU = 7.51 × 10,195 / 53, 643 = 1.427

ε = 1- exp[127 × (1 + 601)] / 1.601 = 0.898 / 1.601 = 0.561 or

$Q = 0.561 \times 53{,}643 \times (1{,}472\text{-}508) = 29 \times 10^6$ Btu/h

Exit gas temperature = $29 \times 10^6 / (176{,}000 \times 0.99 \times 0.3051)$ = 926°F and exit steam temperature is $29 \times 10^6/132{,}000 / 0.676$ = 833°F.

It can be shown that the maximum tube wall temperature is far less than 900°F and hence, tubes will not fail. However, the duty is lower. This is not a bad idea if a plant is willing to accept the lower duty of superheater as a temporary measure.

It can be shown that if the steam flow was reduced to 105,000 lb/h, then in parallel flow, one can achieve an exit steam temperature of 890°F. The maximum tube wall temperature will be less than 950°F and still acceptable. This exercise is left to the reader. Table 9 shows the results.

Example 3

A petroleum refinery is planning to install a thermal fluid heater (paratherm1) utilizing energy from a gas turbine exhaust to preheat the fluid from 250 to 550°F. It has obtained quotes from two suppliers and the data are shown here. Both offer the same duty and same exit fluid temperature. Both vendors use T11 tubes. Cross-section is the same. Plant wants to evaluate the two designs. The vendors have not offered more information. Prices were comparable. In fact, vendor 1 was 5% less in price.

Solution: The first thing that struck the plant engineers was the vast difference in surface areas. Vendor 1 appeared to be attractive as the price was also slightly lower. However, some process engineers felt that more surface area in finned tubes can be misleading as explained in references 1 and 4. Higher ratio of fin surface to tube surface lowers the gas-side heat-transfer coefficient. The product of (*UA*) will be the same if the duty and LMTD are same. Some plant engineers referred to the literature on the fluid and found that the maximum film temperature allowable was 650°F. Hence a calculation was done to check the film temperature in both cases. Let us assume both vendors have sized the exchanger with proven correlations. In other words, let us assume that the surface areas given by them will perform the duty.

In order to compute the maximum film temperature, the maximum heat flux has to be computed. This required computation of tube side heat transfer coefficient at the fluid exit as also the *U* value.

The average $U = Q/A/$LMTD. LMTD in both cases is 350°F. Hence $U_1 = 15.94 \times 10^6 / 7{,}740 / 350 = 5.89$ Btu/ft^{2}h°F and $U_2 = 15.94 \times 10^6 / 350 / 4{,}895 = 9.30$ Btu/ft^{2}h°F.

Fluegas properties at 950°F and 750°F (maximum and average fluegas temperatures are shown below. Tube-side properties at average fluid temperature and maximum fluid temperature are also shown below.

At average paratherm 1 temperature of 400°F, $Cp = 0.67$, $\mu = 1.9$, k = 0.055 and at 550°F, $Cp = 0.77$, $\mu = 0.58$, $k = 0.055$.

Hence, average fluid-transfer coefficient = $2.44 \times (80{,}000/5)^{0.8} \times (0.67/1.9)^{0.4} \times 0.055^{0.6}/1.77^{1.8} = 233$ Btu/ft^{2}h°F

And maximum fluid heat transfer coefficient at 550°F is: $2.44 \times (80{,}000/5)^{0.8} \times (0.77/0.58)^{0.4} \times 0.053^{0.6} / 1.77^{1.8} = 387$ Btu/ft^{2}h°F

Maximum heat flux inside tubes: vendor 1:

$6.21 \times (950\text{–}550) \times 7{,}740 \times 12 / (3.14 \times 1.77 \times 15 \times 10 \times 8.5) = 32{,}550$ Btu/ft^{2}h and for vendor 2, it is 23,257 Btu/ft^{2}h (average gas-side heat-transfer coefficients were corrected for gas temperature at inlet)

One has to be careful using vendor 1, because the film temperature is close to the limit of 650°F. Small variations in *U* around tube periphery, non-uniformity in fluegas flow or temperatures can cause film temperature to be easily exceeded. Hence, the plant can consider vendor 2 a better and safer design. Vendor 1 may be asked to use smaller fin density and quote again. It may be noted that film temperatures cannot be measured. More often, they are calculated as shown. If the issue of film temperature had not been addressed, plant would have purchased vendor 1's design and would have run into problems in operation later. Plants will do better to ask fluid heater vendors to provide film temperature calculations.

Example of a fire tube boiler performance

In order to obtain the performance of any boiler components, the *U* value must be obtained first. This is a rather tedious calculation, if done manually, because fluid properties vary with temperature and analysis. Hence, a simplified approach is in order. Plant engineers are advised to start with these simplified calculations and with programming skills, develop calculation modules for boilers in their plants. This article gives several examples of how using the simplified approach plant engineers can check the accuracy of any water tube or fire tube boiler design or components such as superheater and economizer or a fluid heater.

One of the reasons the simplified approach works well in many boiler applications is that the gas-side heat-transfer coefficient governs the overall heat transfer coefficient *U,* as shown earlier, and hence, manipulating the variables connected with gas-side variations alone will help evaluate the performance with acceptable accuracy of any evaporator, superheater or economizer or fluid heater. Sometimes calculation of the tube inside or outside coefficient becomes a necessity and hence, Appendices 1, 2 and 3 are provided. The simplified approach for fire-tube waste-heat boiler evaluation will be of interest to plant engineers.

$$\ln [(T_{g1}-t_s)/(T_{g2}-t_s)] = UA/(W_g Cp_g) \qquad \textbf{(14)}$$

As gas side governs *U*, for a given tube geometry (length, number, tube sizes) we can write:

$$UA = K_1 (W_g/n)^{0.8}\, n / (W_g Cp_g) \qquad \textbf{(14a)}$$

Where K_1 is a constant for the given geometry, considering the tube length and diameter and gas properties

Equation (14) becomes:

$$\ln[(T_{g1}-t_s)/(T_{g2}-t_s)] = K_1 n^{0.2}/W_g^{0.2} = K/W_g^{0.2} \quad \textbf{(16)}$$

Where n is the tube count. The effect of gas properties is neglected in this simplified approach. If tube count does not change, then $K_1 n^{0.2}$ can be replaced by K, another constant. These simplifications work well for clean gases and when direct radiation from flame or high non-luminous heat transfer coefficients are absent.

Using the above equation, one can predict several aspects of a fire-tube waste-heat boiler performance:

1. Effect of steam pressure
2. Effect of plugging of tubes
3. Effect of change in gas flow
4. Effect of gas inlet temperature.

Example 4

A fire-tube waste-heat boiler generating steam from hot air has been purchased with the parameters as shown in Table 12, Column 1. However, the plant is operating as shown in Column 2 at a lower steam pressure and at lower capacity due to various reasons. Tube geometry data are available as shown. How can we find out if the boiler is performing well or sized properly using the simplified approach? In Case 3, 15% of the tubes were plugged for leaks. What will be the performance then with the design gas flow?

Solution: Typically steam side flow measurements and low temperature gas, fluid temperatures are more reliable than gas flow or high temperature measurements. Hence, in such simulation studies, the fluegas flow is typically worked out from energy balance. This example also shows how one can find out the effect of steam pressure on an evaporator performance.

Case 2: The values shown are as measured in the field. Using these we have to check if the design case performance can be achieved. 4.93 million Btu/h is the energy absorbed by steam using the steam flow and enthalpy data with zero blowdown.

For a quick estimate of airflow in operating case, from Appendix 3, we can estimate the gas specific heat at the average gas temperature of (1,000 + 525) / 2 = 763°F as 0.2592 Btu/lb°F.

Then gas flow will be: 4.93 × 10^6/ [0.2592 / (1,000-525)] = 40,040 lb/h

Let us first compute K.

$\ln[(1{,}000-448) / (525-448)] = K/40{,}042^{0.2}$ or $K = 16.4$.

Use this to check if design performance can be achieved. Let us see if exit gas temperature of 615°F can be obtained with the stated gas flow of 70,000 lb/h at 1,200°F and at 615 psia.

Using Equation (16) again, $\ln[(1{,}200-489 / (T_{g2}-489)] = 16.4 / 700{,}00^{0.2}$ or $T_{g2} = 611$°F

The supplier has given 615°F, which is close. The measured gas pressure drop between the boiler inlet and exit is 1.0 in. wc. The design pressure drop will be approximately $(70{,}000/40{,}000)^2 \times 1 = 3.1$ in. wc across the tubes. Considering the higher average gas temperature the gas pressure will be higher, close to the 3.4 in wc, the design value stated. Hence the design/proposal data are reasonable, assuming the measurements in case 2 are good.

Case 3: If 15% of tubes are plugged, what will happen to the duty and gas pressure drop with the design gas flow and inlet gas temperature?

Let us check the revised K value for the original design. $K = 16.4 \times (361/425)^{0.2} = 15.88$

Using Equation (16), $\ln[(1{,}200-489) / (T_{g2}-489)] = 15.88/70{,}000^{0.2} = 1.705$ or $T_{g2} = 619$°F

The duty or steam flow after plugging will be (1,200-619) / (1200-611) = 0.986 × 100 = 98.6% of design value. The gas pressure drop will be about $(425/361)^2 \times 3.4 = 4.6$ in wc. Gas pressure drop will be a major concern rather than decrease in duty with 15% plugging.

Hence using such simplified estimates backed up by one set of good field data, one can get a good idea of off-design performance of fire tube or water tube boilers.

APPENDIX 1

Tube-side heat-transfer coefficient. Simplified estimates for heat transfer coefficients of single-phase fluids inside tubes are presented in

Grimson's Values of B and N

S_T/d	1.25		1.5		2.0		3.0	
S_L/d	B	N	B	N	B	N	B	N
Stagger								
1.25	0.518	0.556	0.505	0.554	0.519	0.556	0.522	0.562
1.5	0.451	0.568	0.460	0.562	0.452	0.568	0.488	0.568
2.0	0.404	0.572	0.416	0.568	0.482	0.556	0.449	0.570
3.0	0.310	0.592	0.356	0.580	0.440	0.562	0.421	0.574
Inline								
1.25	0.348	0.592	0.275	0.608	0.100	0.704	0.0633	0.752
1.5	0.367	0.586	0.250	0.620	0.101	0.702	0.0678	0.744
2.0	0.418	0.570	0.299	0.602	0.229	0.632	0.198	0.648
3.0	0.290	0.601	0.357	0.584	0.374	0.581	0.286	0.608

Table C1: Gas analysis and properties

How are the gas properties C_p, μ, and k estimated for a gaseous mixture? Determine C_p, μ, and k for a gas mixture having the following analysis at 1650°F and 14.7 psia.

Gas	Vol%	C_p	μ	k	MW
N_2	80	0.286	0.108	0.030	28
O_2	12	0.270	0.125	0.043	32
SO_2	8	0.210	0.105	0.040	64

Ref. 1. In fire tube boilers, the fluegas-side heat-transfer coefficient governs the overall heat transfer coefficient U. An idea of the tube-side coefficient h_i in a superheater will help determine its tube wall temperature and pressure drop. In a fluid heater, it helps to determine the film temperature of the thermic fluid.

Tube side coefficient may be estimated by the following:

$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$

$Nu = h_i d_i/12k$

$Re = 15.2 w d_i/\mu$

[$Re = 3{,}600\rho\ V d_i/\mu/12$. $V = 576\ w/[3{,}600\pi\ d_i 2\rho$.

Simplifying $Re = 15.2\ w/d_i/\mu$]

$Pr = \mu Cp/k$

All properties estimated at fluid bulk temperature.

Simplifying further, $h_i = 2.44\ w^{0.8}\ C/d_i^{1.8}$

where factor $C = (Cp/\mu)^{0.4}\ k^{0.6}$

C is available in tables and charts in order to quickly estimate hi for various fluids (see Refs. 1 and 2).

a: For wet air (% volume H_2O = 1, N_2 = 78, O_2 = 21)

Importance of streams in economizer and superheater

One of the important pieces of data to be furnished by boiler vendors in their description of a superheater, economizer or a fluid heater is streams, or the number of tubes carrying the entire steam or water flow of a boiler. Often one is required to estimate the steam or water velocity inside the tubes, heat transfer coefficient, pressure drop or tube wall temperatures. Many boiler vendors do not provide this crucial data or drawings which show baffle plates in the header, if used. Hence when confronted with solving a tube failure problem in a superheater, one gets stuck. Partitions in headers can mask this data and hence plant engineers should get this data from the boiler vendor for future analysis. The Figure 10 shows a few examples of what streams are.

APPENDIX 2

Heat-transfer coefficients outside plain tubes

Fishenden and Saunders equation for convective heat transfer coefficient hc outside plain tubes takes the form:

$Nu = 0.35 Fh Re^{0.6} Pr^{0.3}$

The Fh factor depends on the tube arrangement, whether inline or staggered, and is shown in Table B1. It can be seen that the correction factor is nearly the same for both inline and staggered when Sl/d is above 2, which is the arrangement typically used in boiler practice. It also is used to improve ligament efficiency in drums. However if fluegas pressure drop is considered, it is far higher for staggered compared to inline arrangement. Hence, rarely will one see a staggered arrangement for plain tubes, because from a heat-transfer perspective, there is no significant benefit while operating costs in the form of fan power consumption will be much higher [*1,2*]

A conservative correlation used for both inline and staggered arrangements is:

$Nu = 0.33\ Re^{0.6} Pr^{0.33}$

$Nu = h_c d/12k$

$Re = Gd/12\mu$

$Pr = \mu Cp/k$

All gas properties for heat transfer are evaluated at gas film temperature which is the average of gas and tube wall temperature and lower than the average gas temperature.

Simplifying the above,

$h_c = 0.9 G^{0.6} F_g/d^{0.4}$

where

$F_g = k^{0.67}\ Cp^{0.33}/\mu^{0.27}$

Another correlation widely used is that of Grimson's [*1*]

$Nu = BRe^N$

where B and N are shown in Table B1.

Examples of using these correlations are given in Refs. 1 and 2.

Finned tube bundles

Correlations for finned tube bundles are more involved and shown in Refs. 1 and 2 with worked out examples.

The gas property factor affecting gas side heat transfer is given by [*1,2,4*]

$F_g = k^{0.67}\ Cp^{0.33}/\mu^{0.32}$

Steam Balancing: The First Step in Steam Optimization

The ability to achieve an optimal steam balance can help to improve the overall thermal cycle efficiency of any steam-production system

Kelly Paffel
Inveno Engineering, LLC

IN BRIEF

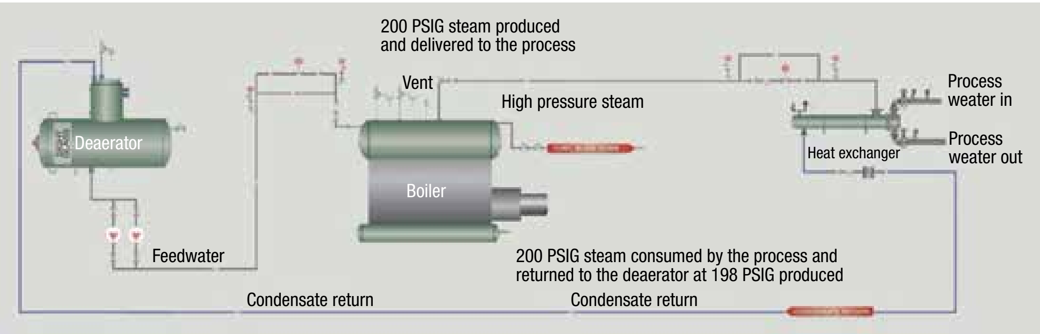


FIGURE 1. Shown here is a perfect steam balance. This scenario is an aspirational goal for process

In any chemical process plant that produces steam, carrying out a steam balance is the most efficient way to improve knowledge of all aspects of the overall steam system, including steam generation, distribution, end users and condensate-recovery systems. Carrying out a steam balance is a necessary first step in any effort to optimize and manage overall steam generation.

For instance, the valuable knowledge gained from developing or updating a steam balance can help process engineers to develop a road map that will allow the steam system to be used in the most efficient way. Such an effort also provides essential insight that can be used to increase the overall thermal-cycle efficiency of the steam-generation system. Ideally, every plant should strive to achieve the highest possible thermal-cycle efficiency; the steam balance provides the information needed to achieve this objective.

An optimal steam balance ensures that the end users — that is, the steam-consuming processes — can consume the correct amount of energy at the correct steam pressure and temperature, with the required steam quality. A system that has achieved an optimal steam balance has no energy losses that might otherwise occur from steam leakage, excessive low-pressure steam venting, flash steam venting and condensate loss.

Establishing the correct steam balance can be very challenging because so many different dynamics are at work in any given steam system. These include modulating steam loads, variable production times, unaccountable losses, insulation inefficiencies, turbine operation and more.

Figure 1 shows a nearly perfect steam balance in a system that produces steam at 200 psig and delivers it to the process. The process consumes the entire 200 psig (latent energy) of the steam while the condensate (sensible energy) is removed from the process. The end user's process requires the latent energy contained in the steam. When that latent steam is released, there is no temperature or pressure variance, and the condensate that contains the sensible energy is returned to the deaerator operation at a pressure of 30 psig or higher. The condensate system that is operating at 198 psig returns the condensate (using a high-pressure return system) back to a high-pressure deaerator system. This dearator system delivers the feedwater at an elevated temperature (198 psig at 387°F) into the boiler.

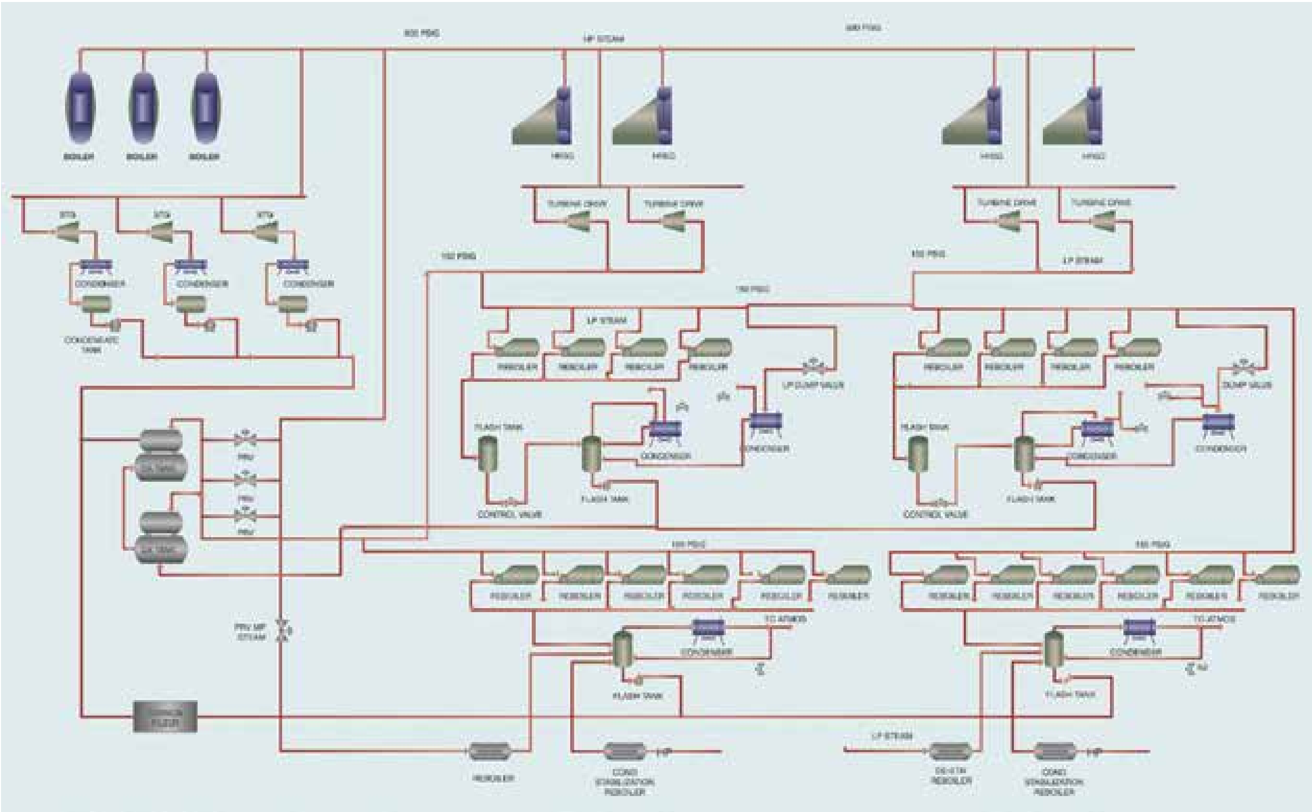


FIGURE 2. Different methods can be used to recover the condensate under pressure, thus saving energy and reducing emissions from the plant. For instance, switching from a low-pressure deaerator to a high-pressure deaerator, with some changes to the condensate line, allowed the return of condensate from non-modulating processes to the high-pressure deaerator, resulting in higher thermal-cycle efficiency for the steam system

An optimal steam balance can achieve the following objectives:

1. Ensure high sensible energy content in the condensate
2. Reduce flash steam
    a. Eliminate the need for flash steam recovery (The deaerator will consume the small percentage of flash steam)
2. Allow for smaller-diameter condensate piping
3. Enable higher feedwater temperatures, and thus a higher boiler efficiency
4. Yield higher thermal-cycle efficiency for the steam system

The ideal system shown in Figure 1 is hard to achieve due to the actual process conditions and the design of the condensate-drainage system (using steam traps or condensate control valves), which need different pressures to remove the condensate from the process devices. To achieve a high thermal-cycle efficiency for the steam system, the plant should strive to achieve a steam system with a condensate system that operates at a high elevated pressure (as shown in Figure 1).

In reality, a perfect steam balance cannot really exist for several reasons. First, modulated steam pressures or steam flows to the process will reduce the differential pressures for the devices in the condensate drain (such as the steam trap stations or condensate control valve). Also, the economics of such condensate-drain devices will change (in terms of an increase in size and cost) at lower operating pressure differentials. For example, the condensate system dynamics can limit the plant in terms of how high the condensate pressure can be maintained in the condensate-return system.

The consumers (end users) of the steam have their own demand for the required quantity, and they expect 100% steam quality at a given specific pressure and temperature. It is up to the plant to manage the steam balance in a way that meets end users' requirements. However, that is easier said than done, because the end users' steam demand constantly varies during operation of the steam system. Achieving high thermal-cycle efficiency for the steam system requires that operators develop a well-documented steam balance.

The challenge at hand

Too often, knowledge of the steam system becomes segmented. For instance, the boiler plant personnel have deep knowledge of how to operate the boiler plant, while process personnel have a deep understanding of the how to operate the process steam system. Sometimes, the steam distribution and condensate system are not considered a focus area in the steam-system operation. Similarly, too often, the condensate system is omitted from the total steam-system balance, even though this part of the system accounts for roughly 16% of the overall energy in the steam vapor. Striving to achieve a proper steam balance allows process operators to understand and recover the flash steam by some means, to ensure a high steam thermal cycle efficiency.

The typical steam system has a large number of different piping and

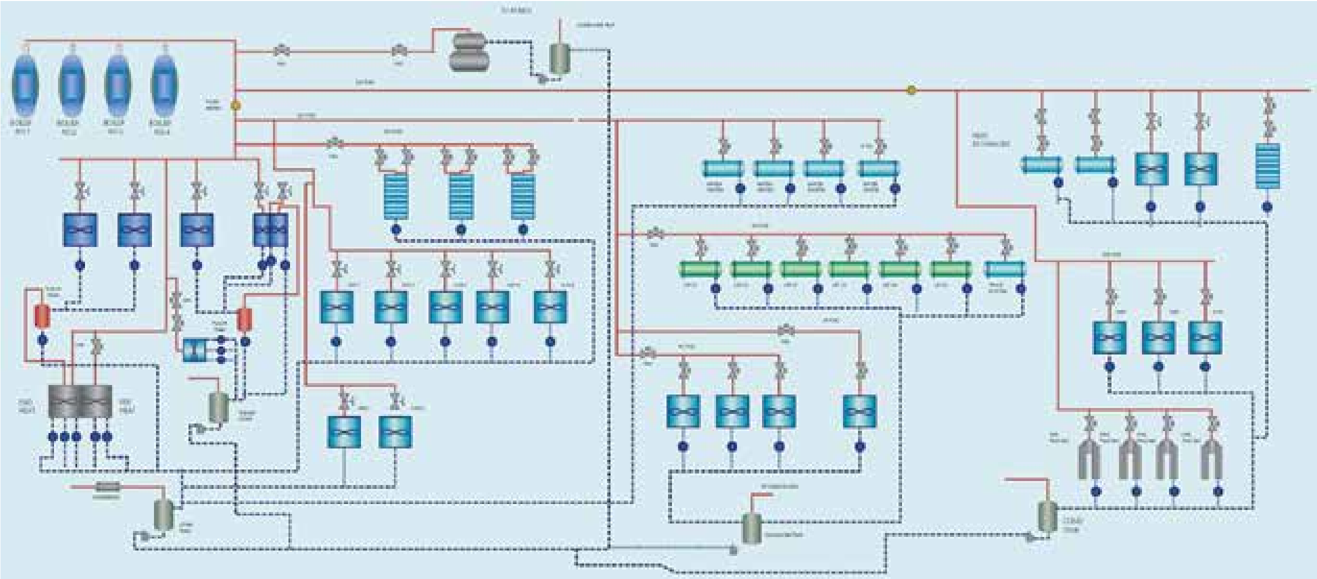


FIGURE 3. A system that has achieved an optimal steam balance has no energy losses that might otherwise occur from steam leakage, excessive low-pressure steam venting, flash steam venting, condensate loss and more

instrumentation diagrams (P&ID) prints, which are often located somewhere in the facility (but not necessarily stored in a centralized or organized fashion). For many facilities, such diagrams are often established over many years, by many different engineers, with different formats, thus making it difficult to establish a single or dual set of prints. Computer-aided design (CAD) prints are generally not kept updated, which makes the task even more difficult to accomplish. Nonetheless, the effort to develop and maintain a current steam-balance print can provide significant payback.

Achieving a steam balance

In general, it is impossible to optimize a steam and condensate system

without a steam balance, and this requires a complete understanding of the system. The easiest and best way to truly understand the steam system is to create a steam balance flow diagram.

The steam-balance flow diagram can be accomplished in many different ways, such as a fully devolved document completed in different technical software systems, or a simple flow diagram completed with a basic graphics program. The key point is to develop a steam-balance document that plant personnel can use.

WHAT A STEAM BALANCE PROVIDES

1. Improved knowledge of the steam and condensate system
2. Ability to set a roadmap for change to improve system performance
3. Increased energy efficiency
4. Reduced emissions
5. Increased reliability

End results of a steam balance

Implementing a perfect steam balance — one that accounts for steam generation, distribution, end-user requirements and condensate recovery — can be an extremely challenging goal in any industrial steam plant operation. An industrial plant can have several different steam-generating sources and a multitude of end users with varying steam pressure and steam flow demands. The steam turbine operation for electrical generation or drive units plays an important part of the balance, and the operation of the steam-pressure-letdown valves (pressure-reducing valves) needs to be minimized to ensure maximum steam flow to the steam turbine operation.

Four types of condensate-recovery systems are typically added into the balance, making the system dynamics even more complex. To meet production requirements, plants typically continue to update and make process changes over time, and all such changes will affect the steam balance. Therefore, steam balancing must be viewed as a continuous program — not a one-time effort.

A proper steam balance will also eliminate the waste associated with venting "unusable" low-pressure steam to the atmosphere, by instead balancing the steam flow more effectively to the end users (steam turbines, heat exchangers, reboilers) and then discharging the condensate/flash steam to the downstream steam cascade systems. This results in a final steam process that has the correct amount of low-pressure steam. If such a cascade system cannot be accomplished, then the operator may opt to use a thermocompressor to upgrade the low-pressure steam to medium-steam-pressure grids until the desired balance is achieved in the system.

Steam balance Example 1. The following steam balance (Figure 1) was accomplished in a simple software graphics program format, but it resulted in a substantial reduction in energy and emissions. The steam balance indicated that a pressurized condensate system could easily be instituted into seg-

ments of the process system using the current condensate system, incurring relatively minor capital costs but saving millions of dollars per year over the long run.

Steam balance Example 2. In the second example, a steam balance determined that a few minor steam-piping changes allowed low steam pressures to be consumed by end users, thus reducing the flash steam losses. The changes improved condensate drainage and further reduced the flash steam venting. The result was increased steam-system thermal-cycle efficiency with a reduction in energy and emissions and increased overall reliability.

Steam balance Example 3. Figure 2 shows different methods to recover the condensate under pressure, which can help save energy and reduce emissions for the plant operation. Switching from a low-pressure deaerator to a high-pressure deaerator, with some changes to the condensate line, allowed the return of condensate from non-modulating processes to the high-pressure deaerator, resulting in higher steam-system cycle efficiency.

Steps for a steam balance

A steam-balance flow document (such as that shown in Figure 3) provides all the required steam and condensate information, capturing relevant information about the steam flows, pressures, end users, pressure-reduction stations, turbines, boilers, condensate tanks and more. The more detail added into a steam-balance flow diagram, the more important and valuable the document becomes to the plant operation.

Shown below are some of the essential items that should be properly documented during the process:

1. All boilers or steam generators
   a. Steam output
   b. Operating steam pressures
   c. Safety valve set pressures
2. Deaerator system details
   a. Operating pressures
   b. Steam flows
3. Makeup water system for the deaerator
   a. Flowrates
   b. Average temperatures
4. Steam turbines
   a. Supply pressures
   b. Extraction pressures
   c. Electrical or drive output
5. Steam headers by operating pressure
6. Steam pressure-letdown stations
   a. Inlet and outlet pressures
   b. Maximum and minimum flowrates
7. End users or consumers
   a. Energy requirements (Maximum and minimum)
8. Condensate headers
   a. Operating pressures
   b. Flowrates
9. Flash tanks
   a. Integration into the system
   b. ASME stamping
10. Condensate tanks
    a. Venting or not venting
    b. Pressure ratings
11. Other site-specific details that can help support the project

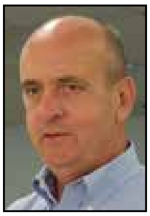
The list will grow as the steam balance process continues.

Closing thoughts

Every plant, regardless of size, from a small food processing plant to a large petroleum refinery, needs to prepare a steam balance in a format that works to support the plant's operation. Conducting a steam balance does not necessarily require a complex software system in order to be beneficial to the steam system manager; rather, it can be accomplished using a simple graphic software package. Whatever method is selected, carrying out a steam balance is the first step in increasing overall steam system thermal-cycle efficiency, which will reduce energy use and emissions and increase overall system efficiency. ■

Edited by Suzanne Shelley

Author



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Improving Data Analytics in Batch Manufacturing

Producing a perfect batch is easy for some products but harder for others. Using analytics to dig into production data can help operators identify where variability might be creeping into a process

Jon Peterson
Seeq

For many batch manufacturers in the chemical process industries (CPI), creating a "perfect" batch — one for which everything works just right and all quality specifications are met — is a key objective. While a batch is being produced, all the conditions associated with it should be recorded as a matter of course and, ideally, those conditions should be repeated every time.

Going back and looking at earlier efforts (as captured by a data historian) can provide additional insight. Identifying which batches turned out perfect and reviewing the production data associated with those production runs is a great way to create critical process parameter (CPP) profiles (with acceptable tolerances). These can then serve as guides to create perfect batches every time.

Conceptually, this approach makes sense, and many manufacturers find it a useful way to control and maintain production. It may work most of the time with most products. But implementing this concept when working with more troublesome products and processes can be very difficult, particularly during the production of certain complex chemicals and pharmaceuticals.

Try as they might to control all the CPPs of a recipe to positively impact product quality (as measured by a group of critical quality attributes or CQAs), manufacturers still create batches that are out of specification (or "off-spec"). In many cases, it often becomes clear that the number of variables, and the cause-and-effect relationships connecting CPPs and CQAs for a given product, are more complex than realized. Some variables might prove to be more important than initially thought, while others will not matter as much. Other variables will prove to be capable of affecting the outcome, but might not be covered adequately by the existing instrumentation or even recognized.

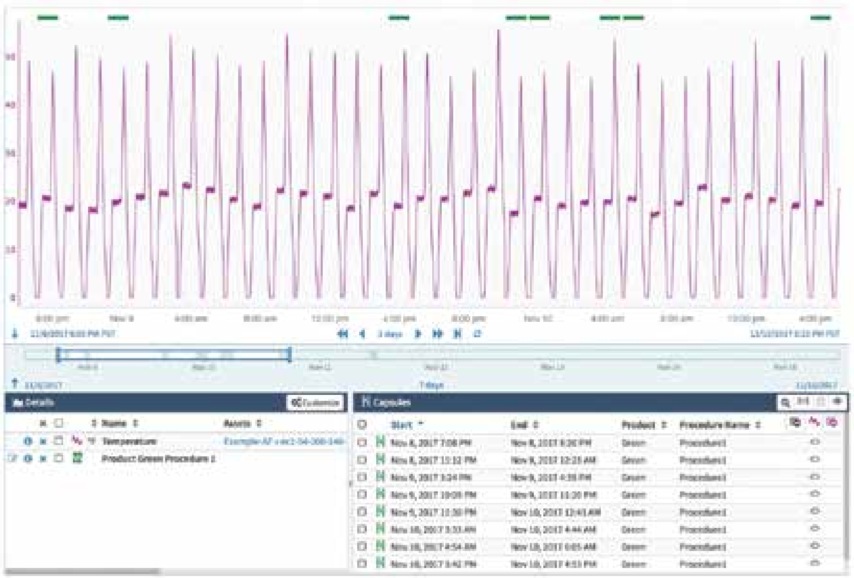


FIGURE 1. Historians typically record operating data continuously, so the data for a given product and batch have to be identified. The green bars shown at the top identify the relevant data segments for the CPP being analyzed for the specific product

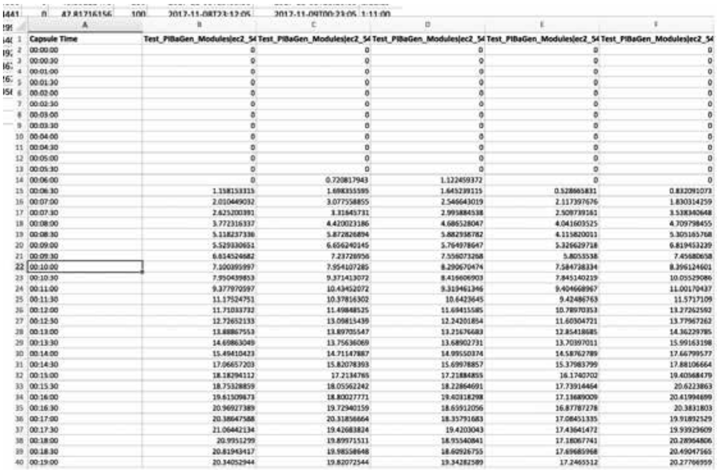
Consistent batch-after-batch success requires first acquiring and storing the necessary data about the product — with the required level of detail — and then analyzing the data carefully to yield actionable insights.

Working in the real world

Consider a hypothetical example. Picture a typical process unit, such as a reactor. It is a jacketed, stainless steel tank — so it can be heated, cooled and pressurized as needed. It has an agitator, inlet pipes, outlet pipes, pressure instruments, temperature sensors and pH sensors. Various batch recipes call for it to be used when making a few dozen different products, with production times ranging from a few hours to a week, per batch.

While performing a unit procedure for a given product, there will normally be at least 15, and perhaps 20, process variables instrumented and recorded by the data historian. To make the example more specific, Product A is made in this reactor at least 25 times per year, so roughly once every two weeks. A run of Product A takes about 16 hours from start to finish, plus additional time for equipment setup and cleanup.

In the data historian, there are batch records dating back more than two years, covering 60 batches of Product A produced in this reactor. Perhaps two batches each year



	A	B	C	D	E	F
1	Capsule Time	Test_PIBaGen_Modules\ec2_54	Test_PIBaGen_Modules\ec2_54	Test_PIBaGen_Modules\ec2_54	Test_PIBaGen_Modules\ec2_54	Test_PIBaGen_Modules\ec2_54
2	00:00:00	0	0	0	0	0
3	00:00:30	0	0	0	0	0
4	00:01:00	0	0	0	0	0
5	00:01:30	0	0	0	0	0
6	00:02:00	0	0	0	0	0
7	00:02:30	0	0	0	0	0
8	00:03:00	0	0	0	0	0
9	00:03:30	0	0	0	0	0
10	00:04:00	0	0	0	0	0
11	00:04:30	0	0	0	0	0
12	00:05:00	0	0	0	0	0
13	00:05:30	0	0	0	0	0
14	00:06:00	0	0.720817943	1.122459372	0	0
15	00:06:30	1.158153315	1.698355595	1.645239115	0.528665831	0.832091073
16	00:07:00	2.010449032	3.077558855	2.546643019	2.117397676	1.830314259
17	00:07:30	2.625200391	3.31645731	2.995884538	2.509739161	3.538340648
18	00:08:00	3.772316337	4.420023186	4.686528047	4.041603525	4.709798455
19	00:08:30	5.118237336	5.872826894	5.882938782	4.115820011	5.305165768
20	00:09:00	5.529330651	6.656240145	5.764978647	5.326629718	6.819453239
21	00:09:30	6.614524682	7.23728956	7.556073268	5.8053538	7.45680658
22	00:10:00	7.100395997	7.954107285	8.290670474	7.584738334	8.396124601
23	00:10:30	7.950439853	9.371413072	8.416606903	7.845140219	10.05529086
24	00:11:00	9.377970597	10.43452072	9.319461346	9.404668967	11.00170437
25	00:11:30	11.17524751	10.37816302	10.6423645	9.42486763	11.5717109
26	00:12:00	11.71033732	11.49848525	11.69415585	10.78970353	13.27262592
27	00:12:30	12.72652133	13.09815439	12.24201854	11.60304721	13.77967262
28	00:13:00	13.88867553	13.89705547	13.21676683	12.85418685	14.36229785
29	00:13:30	14.69863049	13.75636069	13.68902731	13.70397011	15.99163198
30	00:14:00	15.49410423	14.71147887	14.99550374	14.58762789	17.66799577
31	00:14:30	17.06657203	15.82078393	15.69978857	15.37983799	17.88106664
32	00:15:00	18.18294112	17.2134765	17.21884855	16.1740702	19.40568479
33	00:15:30	18.75328859	18.05562242	18.22864691	17.73914464	20.6223863
34	00:16:00	19.61509673	18.80027771	19.40318298	17.13689009	20.41994699
35	00:16:30	20.96927389	19.72940159	18.65912056	16.87787278	20.3831803
36	00:17:00	20.38647588	20.31856664	18.35791683	17.08451335	19.91892529
37	00:17:30	21.06442134	19.42683824	19.4203043	17.43641472	19.93929609
38	00:18:00	20.9951299	19.89971511	18.95540841	17.18067741	20.28964806
39	00:18:30	20.81943417	19.98558648	18.60926755	17.69685968	20.49047565
40	00:19:00	20.34052944	19.82072544	19.34282589	17.2465512	20.27766959

FIGURE 2. Importing the data into a platform such as Excel provides the means to extract the relevant CPPs, but the process is tedious

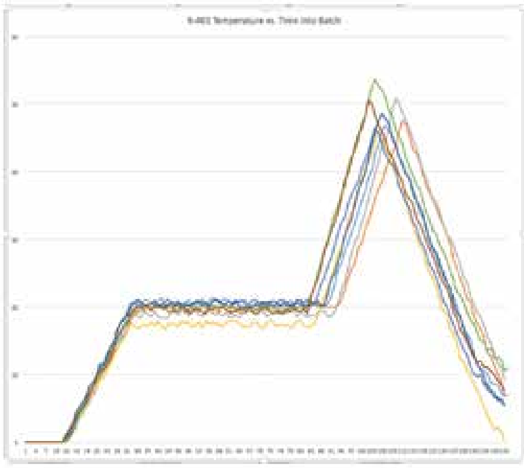


FIGURE 3. With some effort, a spreadsheet can help generate graphs of the specific CPPs so they can be compared directly against each other

fail to meet specifications and are discarded. Running a replacement batch delays the schedule by at least two shifts.

The recipe for Product A has five main steps where ingredients are added, and then the reactor is heated and cooled. Process experts have identified six CPPs that need to be controlled within specified limits during the unit procedure for a batch to meet specifications. The process is generally stable and controllable enough to run within the lines most of the time.

Nonetheless, some batches fail to meet the specifications, even while apparently keeping CPPs "in spec." This is vexing since running within the limits on all six CPPs is supposed to produce an acceptable batch. Those limits reflect what the company's process engineers believe are the required attributes observed in the best batches, but sometimes they still don't produce the desired result.

FIGURE 4. A sophisticated analytical platform (compared to just the use of a simple Excel spreadsheet) can help users capture the CPPs easily, pulling them out of the historian automatically

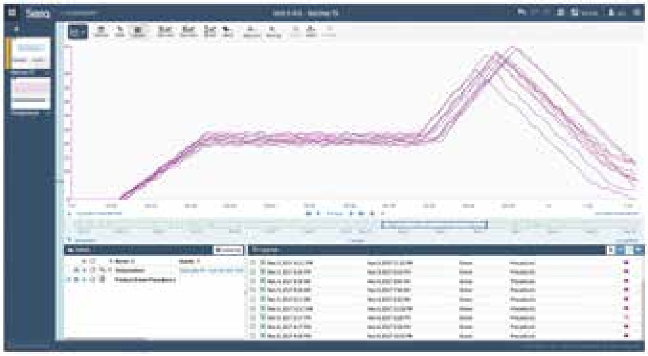


FIGURE 5. The data analytics platform can easily create superimposed graphs using automatic ranging and scaling capabilities. This allows process engineers to quickly recognize which curves tend to form a tight group, and the platform can aggregate all of these curves into an ideal profile for that CPP. This becomes the reference profile for that CPP for that product manufactured using that equipment

A more methodical approach

To solve the puzzle, an enterprising process engineer may gather up data from the reactor's control system and data historian (Figure 1). Loading it into Microsoft Excel or similar software is a tedious but manageable task to extract data and create graphs (Figures 2 and 3), and to compare specific attributes tied to CPPs across multiple identical unit procedures.

Batch by batch, it is possible to examine the solution temperature, the agitator speed or other factors that might be suspected of causing a problem. This approach sometimes works, and it might even generate some possible answers, but it will probably be necessary to dig deeper. The practical limits of manual analysis with Excel for complex processes will soon be encountered.

The next level is a more sophisticated data-analytics approach. This may be a function built into a data historian, or more typically, a third-party application designed to work with data from the historian. These applications make analysis easier by extending number-crunching capabilities beyond a normal spreadsheet, combined with mechanisms to aggregate data.

Ongoing technology advances

Ongoing advances in analytics software have greatly simplified the infrastructure required to implement data-analytic applications. Cumbersome techniques, such as spreadsheets, data cubes and data warehouses, are no longer needed. Modern data-analytic platforms can run on typical office computers, communicating directly with the historian and extracting data as needed for any computations.

Returning to the example discussed above, process engineers watch six CPPs connected to unit Procedure A. Using data recorded in the historian from the 60+ unit procedures (Figure 4) that generated good batches with acceptable specifications on all CQAs, it is a simple matter to graph the six variables for all the unit procedures. Curves for each CPP from all 60 unit procedures can be superimposed on each other using identical scales.

Using this approach, it is easy to see whether the curves tend to form a tight group, or if they spread out, showing different values at various times for a given CPP (Figure 5). The data-analytics platform can aggregate all these curves into an ideal profile for that CPP. This then becomes the reference profile for that CPP, for that product manufactured, using that equipment. This is necessarily specific, given the importance of only comparing "like data."

Using the reference profile, it is possible to generate upper and lower tolerance limits — or boundaries — based on an appropriate value, such as two or three standard deviations (Figure 6). Exactly where these boundaries need to be set will ultimately be determined by the process and how variability of this CPP affects the final product, but using this approach is a good place to start. There is no advantage in making every tolerance profile equally tight. Allowing wide tolerances for variables that still support CQA requirements will ultimately create a process that is easier to control.

This same procedure can be repeated for every CPP to create a reference profile and a set of boundaries for each of those variables. Data for a CPP can even be aggregated into a single value, which can become a useful metric for comparing many batches. Histograms of these metrics provide a quick view of process variability.

When the process is thus char-

Process operators can advance theories of what might be happening, and use data-analytics tools to see if the operating experience supports a potential cause-and-effect relationship. Today's tools allow such theories to be tested with relative ease

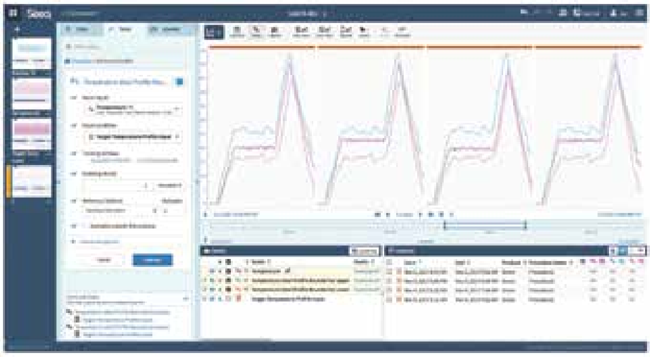


FIGURE 6. Using new-found insight, the most successful, consistent batches can be examined in depth. Using the reference profile, it is possible to generate upper and lower tolerance limits based on an appropriate value, such as two or three standard deviations

FIGURE 7. Once the limit bands are established — using data from on-specification and high-yielding batches — it becomes a simple matter to compare any batch, successful or not, to those limits and to gain insights by looking at various excursions from known good values and resulting off-spec batches

acterized — using data from on-spec and high-yielding batches — it is possible to gain insights by looking at various excursions from known good values and resulting off-spec batches (Figure 7). Once there are reference profiles for every CPP, it is easier to tell where things might be going wrong. Instructions can be written to look for specific conditions.

One example would be a set of instructions to find every batch where the temperature change at the beginning of the crystallization phase ran from the high to the low extreme. With the right data-analytics application, these types of queries can be constructed without creating complex formulas or macros.

Such analysis can also identify those parameters that are controlled too tightly. For instance, temperature does not have to be controlled with the same level of precision at every phase of a unit procedure. In fact, the tolerance range boundaries at one point can be increased, while at another they need to be tightened. Matching the boundaries more appropriately to the actual needs of the process reduces costs while improving batch-acceptance rates.

Applying the tools

This kind of analysis cannot solve ev-

erything by itself. It can work with the data available, but it cannot create meaningful insight without sufficient information. As mentioned at the beginning of this discussion, manufacturers do not always measure everything they should. The temperature at a specific point in the reactor might be a very important CPP, but unless there is a temperature sensor capturing readings at that point, there will be no data.

Similarly, such analysis cannot suggest hypotheses, nor can it draw conclusions, but with these tools in hand, the engineers carrying out the analysis can begin to consider what-if scenarios. This is where the human element becomes important. Process experts can advance theories of what might be happening, and then use the data-analytics tools to see if experience supports a given cause-and-effect relationship. The advantage of today's tools is the relative ease with which such theories can be tested.

Extending our example, let's say Product A is a crystalline substance that must be precipitated from a solution, beginning 14 hours into the unit procedure. The crystallization process tends to vary from batch to batch, which affects yield, but no one has been able to identify exactly what is happening during the process to account for this variability. Engineers looking at the situation have different theories:

- Jim argues that it relates to the temperature at the start of the crystallization phase — he says it should be higher
- Anne thinks the rate of temperature change is key, and the cooling action should be faster
- Chris sees it as a concentration problem caused by an incomplete reaction at an earlier stage

Each of these suggested remedies can be evaluated by performing basic extractions from the larger block of historian data, and by then performing various data analytics.

For Jim, it is possible to look for specific solution temperature values at the critical point in the process. Here are the situations where we were bumping against the upper limit against those where we're at the bottom. How do those compare with overall yield? Is it a clear and direct relationship? Does it suggest there is still another factor influencing the outcome?

For Anne, the slope of the temperature line is critical, and it is easy to separate the steep from the slow. Beginning solution temperature can also be factored in, along with the cooling water temperature and flow. If we can cool more quickly, does it really affect yield?

Maybe Chris is right and we aren't watching the earlier reaction closely enough. What about concentration at the beginning of the crystallization phase? Does it have a significant enough effect on yield to re-examine how it works?

Testing these theories and even hunches against the data requires the ability to look at aggregate effects, with the option of drilling down into the details when necessary. Comparisons must be easy to make, even when multiple factors are involved. Our group of engineers may begin by looking at the unit procedures with the highest yields, and then back into the other variables. Or the approach might be to test each theory individually or in combination. The software should be able to perform regressions and other analytics to show where correlations exist and where they do not.

Jim, Anne and Chris may all be right — the crystallization process needs to start at a higher temperature, but be brought down as quickly as possible. The upstream process may also need to be tweaked. Once the unit procedures where those attributes can be identified have been examined, it's a simple matter to make the necessary adjustments to the process. The fix is easy; it's finding the problem that's hard, unless the right tools are used.

To make this practical, all the raw data must be accessible by the data-analytics tool, and the mechanisms to do the extractions and comparisons must be easy to implement. Data-analytics tools have come a long way in this respect, by offering more intuitive interfaces using drag-and-drop capabilities, rather than requiring users to write equations and macros. It is now easier than ever to find the areas of interest in the data, and to perform the kinds of analysis necessary to test theories.

The human element is critical

Naturally there are limitations. Even the best analytical tools are no better than the quality and consistency of the data being analyzed. The kind of analysis discussed so far works great with clean data. But that often is not available. Real-world process data have gaps, process values flatline at times, process instruments can go out of calibration or a given variable might be missing entirely for a unit process. Analytical tools need to help engineers work with the data as it is, providing mechanisms to account for and work around these issues.

Consistency is essential. In our example where we are looking at 60 unit procedures, all the variables must have been measured and recorded in the same way in every case. If the solution temperature sensor was moved from one part of the reactor to another before Batch 28, it might affect the measurements, thereby reducing the confidence in any conclusions built on that attribute. These things happen, and analytical tools should not be stymied when small obstacles are encountered.

And most importantly, process engineers and experts are needed to advance theories and interpret conclusions. Automated analysis can find correlations, but will seldom identify cause-and-effect, particularly for complex processes. The solution is to pick the right data-analytics tool and put it in the hands of those with a deep understanding of the process. ■

Edited by Suzanne Shelley

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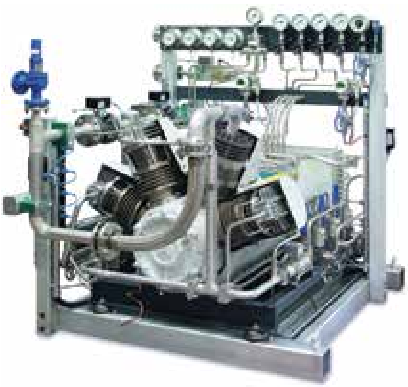
Haver & Boecker


J. P. Sauer & Sohn Maschinenbau


Gebr. Lödige Maschinenbau

Engineers from across the chemical process industries (CPI) will convene June 11–15 in Frankfurt am Main, Germany, for Achema 2018. Over 3,800 exhibitors will showcase some of the world's newest equipment, services and technologies for the CPI, and a concurrent technical conference will include in-depth presentations from experts in all sectors of the CPI. The following Show Preview highlights a selection of Achema's 2018 exhibitors. Attendees at the show can keep up with the events of Achema by reading the *Achema Daily*, a bilingual, daily newspaper published by *Chemical Engineering* (Hall 9.0, Stand E2), in collaboration with Vogel Media (Würzburg, Germany; www.vogel.de). The *Achema Daily* will be distributed to the event's attendees, and also will be available digitally at www.chemengonline.com, for those unable to attend the event.

Double flow-through rate with this 3-D metal filter cloth

The MiniMesh RPD Hiflo-S filter cloth (photo) uses new weaving technology in which a 3-D pore geometry is created that makes industrial filtration processes more efficient, quicker and more economical, says the manufacturer. The open surface over an area is significantly increased due to the weaving structure. The medium's flow-through rate can be doubled when compared to conventional filter cloths having the same pore size. In addition, the flow conditions are optimized and turbulence around the filter cloth is effectively avoided. The pore size within a batch can be calibrated as desired from 5 to 40 µm. Moreover, it is now possible to weave special materials (such as Avesta, Hastelloy, Inconel or titanium) in the small pore-size range, which previously had not been possible. Hall 5.0, Stand C87 — *Haver & Boecker, Wire Weaving and Machine Div., Oelde, Germany*
www.haverboecker.com

Oil-free compressors designed for long service life

The HAUG.Sirius HP 450 (photo) is a powerful high-pressure compressor that is entirely oil-free to ensure excellent gas purity. The hermetically gas-tight construction of the compressor achieves extremely low leak rates and enables four-stage compression of almost any gas, says the manufacturer. With a volumetric flowrate capacity up to 60 Nm³/h, the compressor operates at a suction pressure of 5 bars(g) and a final pressure of 450 bars(g). From the oil-lubricated side, this company offers the Tornado WP3325 B3-5 Bas-Booster-R compressor, which achieves a final pressure of 400 bars(g) and a suction pressure of up to 5 bars(g). With a leak rate of only 0.1 mbar/L/s, this range of models enables the compression of valuable gases, such as helium, with virtually no losses. Hall 8.0, Stand D24 — *J. P. Sauer & Sohn Maschinenbau GmbH, Kiel, Germany*
www.sauercompressors.de

A mixer designed specifically for lithium battery manufacturing

This company has developed a specialized version of its Ploughshare mixer (photo) that is designed to address the challenging quality demands required for manufacturers of lithium-ion batteries (LIBs). For example, the contamination of LIB cathode masses by foreign ions — in particular iron — must be avoided at all costs. Due to the complex geometry of the specialized mixing elements, the elements, along with the mixing shaft and choppers, are equipped with a thin and wear-resistant ceramic coating. Standard coating materials are based on aluminum oxide or tungsten carbide, but they can be adjusted for a specific application. Because batteries may contain toxic components, such as cobalt, the new Ploughshare mixer is equipped with an application-specific sealing system that avoids uncontrolled spillage of fine powders. The mixers achieve homogeneous mixing of LIB cathode materials in a very short time, which is essential for consistent, reproducible LIB quality, says the company. Hall 6.0, Stand C2 — *Gebr. Lödige Maschinenbau GmbH, Paderborn, Germany*
www.loedige.de

Merging safety and security on a single technology platform

The Smart Safety Platform (photo, p. 79) is said to be the world's first integrated solution that combines safety

and security by uniformly tailoring hardware and software to each other. This empowers operators to significantly reduce the complexity of their systems and purchase only what they actually need. The platform also supports integration of existing systems, enabling lower operating costs and very high security of investment. The company works directly with users to jointly select the appropriate hardware and software components to install in plants. Existing solutions from this company can continue to be used or may be upgraded to the latest generation. By migrating to this platform, plant operators can fulfill essential safety standards. The proprietary, self-contained operating system of the safety controllers minimizes the risk of cyberattacks. Backward-compatible software and hardware updates make the system highly future-proof and keep plant safety and security constantly up to date. Hall 11.1, Stand C15 — *HIMA Paul Hildebrandt GmbH, Brühl, Germany*
www.hima.com

HIMA Paul Hildebrandt

Oil-free and space-saving air compressor

The new Contain-Air compressed-air system (photo) provides a source of oil-free compressed air. Integrated inside a standard shipping container, these powerful yet compact units feature a CSG- or DSG-series rotary-screw compressor equipped with an integrated rotation dryer. Since the container can be flexibly positioned anywhere on company property (a flat surface is the only requirement), there is no need for investment in a separate compressor room. These compact compressed-air stations also deliver oil-free compression with a pressure dewpoint down to –30°C. Hall 8.0, Stand A4 — *Kaeser Kompressoren SE, Coburg, Germany*
www.kaeser.com

Kaeser Kompressoren

The launch of explosion-proof variable-speed actuators

This company has launched explosion-proof, variable-speed valve actuators (photo) for use in potentially hazardous environments. The new SAVEx actuators for open-close duty and SARVEx multi-turn actuators for modulating duty, combined with intelligent ACVEx actuator controls, provide full control of motor speed. Variable speed offers significant advantages for challenging valve-control tasks, since it allows the optimum operating speed to be selected for each change of valve position. High positioning accuracy and optimized setpoint control considerably increase the effectiveness of pressure control valves in gas pipelines, for example. Pressure surges and cavitation effects in the pipeline can be avoided by using speed profiles. Actuator speed can also be controlled by an external signal (either 4–20-mA analog or 0–100% digital) to take full advantage of additional control variables or algorithms. A further option is speed synchronization between two actuators. They are available in six sizes, covering torques up to 1,000 Nm. Speed ranges include 6–60 rpm, 12–108 rpm and 24–216 rpm. Hall 8.0, Stand C23 — *AUMA Riester GmbH & Co. KG, Müllheim, Germany*
www.auma.com

AUMA Riester

Ensure security of medicines with this tamper-evident labeler

This company's new tamper-evident labeller (photo) complies with the European Falsified Medicines Directive (FMD) 2011/62/EU, which will become mandatory for the E.U. pharmaceutical industry beginning next year. The new labeler system ensures tamper-proof security of cartons. As an option, a laser or inkjet printer and a vision system of any brand can be integrated to provide each carton with a unique identification for track-and-trace functionality and serialization. The machine is operated with a user-friendly human-machine interface (HMI). The flexible system handles cartons ranging from 50 to 220 mm in width, 15 to 120 mm in height and 40 to 120 mm in length. A small footprint allows the machine to fit into any production area easily. Hall 1.1, Stand E42 — *LSS Etikettering A/S, Randers, Denmark*
www.lss-dk.com

LSS Etikettering

Control small liquid volumes in realtime with this valve

The 567 BioStar control valve is specially designed for the control of small flowrates in the pharmaceutical, biotechnology and food-and-beverage sectors. The new valve is based on this

Herding GmbH Filtertechnik

WEG Germany

Alfa Laval

Fritsch

company's PD design and the moving parts of its actuator are hermetically isolated from the product area by means of a special polytetrafluoroethylene (PTFE) seal. The unique mechanical design of the valve interface allows the actuator to be replaced while pressure is simultaneously applied, and this can be done without contaminating the medium. In addition to the variants with manual and pneumatic actuators that are already available, a motorized version of the valve will also be available in the future. Hall 8.0, Stand F4 — *GEMÜ Gebr. Müller Apparatebau GmbH & Co. KG, Ingelfingen-Criesbach, Germany*
www.gemu-group.com

Safety systems for industrial filtration

Based on this company's FlameStop flame arrester (photo), the Flameless unit is used on the clean-gas side of a sinter-plate filter to provide pressure relief in the event of a flameless explosion. Numerous explosion tests have demonstrated that neither flame nor smoke occur with the clean-gas-side pressure relief in the case of dust explosions in the filter unit. The Sinterplate filter has a sustainable effect as a protection system according to ATEX, and thus as an ignition breakthrough-proof, explosion-decoupling system. The FlameBreak protects property in filtration systems in accordance with ISO 19353, "Safety of Machinery — Fire Prevention and Fire Protection." The concept includes secure fire detection by means of detection cable, the integrated control and signal processing, as well as active firefighting using an extinguishing aerosol. The fire protection concept is suitable for fire-class A, B and C. Hall 4.0, Stand B23. — *Herding GmbH Filtertechnik, Amberg, Germany*
www.herding.de

An app for predictive and preventive motor monitoring

The new WEG Motor Scan (photo) is easily retrofit to the motor via a mounting clamp, and provides cost-effective, realtime monitoring of electric motors using an application (app) on smart devices. On the basis of the read-out operating data, maintenance personnel can plan preventive or predictive maintenance measures. This contributes to a longer service life of the motors and increased system availability. The company is also exhibiting a selection of energy-efficient motors and automation components for the process industry. Among the highlights is the further development of the explosion-proof asynchronous motors of the W22Xd series, which provide the capabilities to meet energy-efficiency class IE4. Also new are the ATEX-certified, geared motors of the WG20 series for zones 2 (gas) and 22 (dust). Hall 9.0, Stand B13 — *WEG Germany GmbH, Kerpen-Türnich, Germany*
www.weg.net

Use these plate heat exchangers in high-pressure processes

The new T25 range of gasketed plate heat exchangers (photo) are flexible for reconfiguration to handle varying heat duties. The T25-B model is specially engineered for applications that require close temperature-range approach and high pressure. The Curve-Flow feature of the T25-B ensures uniform media flow across the entire plate for improved heat transfer and pressure performance in demanding applications, according to the manufacturer. With high thermal efficiency and a minimized risk of fouling, it can offer benefits in many applications, including heating, ventilation and air conditioning (HVAC). The T25-B features an upgraded plate design from its predecessor and also is at lower risk for fouling. Hall 4.0, Stand D4 — *Alfa Laval Mid Europe GmbH, Hamburg, Germany*
www.alfalaval.com

This knife mill can quickly homogenize sample materials

The new Pulverisette 11 (photo) is an industrial-grade knife mill for fast and gentle comminution and homogenization of moist, oily and fatty, as well as dry, soft, medium-hard and fibrous samples. The mill features a motor with power up to 1,250 W and knife blades with up to four cutting edges, resulting in up to 56,000 cutting processes per minute, says the manufacturer. The grinding vessel has up to 1,400-mL capacity, and the adjustable Vario-Lid system can be added for variable volumes. To ensure safe op-

erations, the knife is fastened in such a manner so that it cannot come loose, even if the sample material is very hard or the startup speed is high. The grinding vessel, lid and knife of the Pulverisette 11 can be cleaned easily and are autoclavable for sterile comminution. Hall 4.1, Stand J49 — *Fritsch GmbH, Idar-Oberstein, Germany*
www.fritsch-international.com

This serialization unit has an anti-slip timing device

The new Track-Pack single-block serialization and accumulation unit (photo) is made up of this company's BL A415 labeller and PS 30 case packer. The unit can be equipped with tamper-evident heads to apply self-adhesive tamperproof seals on the closure corners of the cartons. The compact machine also features a patented timing device that sets the cartons apart and positions them correctly on the adjustable toothed belt, which prevents them from slipping. Hall 3.1, Stand G3 — *Marchesini Group, Pianoro, It*aly
www.marchesini.com

Digitalized management of welding processes

The Orbimat 180 SW (photo) is a new welding power-supply solution utilizing Industry 4.0 capabilities to enable unbroken capture and backup of data on a user's local network. Engineers and quality assurance employees with different user levels have access to projects and data at all times, making it possible to keep track of the entire welding process. All welding data and programs for each individual welding process can be accessed, documented, analyzed and optimized for future welding processes. This way, production sequences can be planned better and are also safer and less time-consuming. The Orbimat 180 SW is operated using a 12.4-in. color touchscreen display, or alternatively with a multifunctional control dial. The multilingual menu interface with graphic support makes operation and parameterization of the welding power supply simple and intuitive. Hall 9.2, Stand D10 — *Orbitalum Tools GmbH, Singen, Germany*
www.orbitalum.com

Marchesini Group

Orbitalum Tools

Bosch Packaging Technology

Testa Analytical Solutions

Kelvion Holding

Metall+Plastic

A highly flexible processing system for injection products

The SVP250 LF processing system for injection solutions (photo) features a conical shape that helps to minimize product loss. The system is designed for small batches, ranging from 15 to 250 L. The system includes both a preparation and a storage vessel. Depending on the desired volume, these process vessels can be expanded to four each, in a range of different sizes. The preconfigured architecture allows processing modules to be flexibly installed or exchanged, for instance for handling different temperature-control concepts or feeding different media, such as powders, liquids or gases. Liquid ingredients are automatically dosed by a pump. Since the process vessels are equipped with a gassing module for nitrogen, production can also take place under low-oxygen conditions. The system features a module for two-stage sterile filtration for aseptic preparation, which is situated between the preparation vessel and the storage vessel. It is also equipped with an optional laminar-flow hood, which generates a low-turbulence air flow to prevent particles from entering the filling area. Hall 3.1, Stand C71 — *Bosch Packaging Technology GmbH, Waiblingen, Germany*
www.boschpackaging.com

Characterize challenging samples with this DRI detector

The AYE differential refractive index (DRI) detector (photo) provides high-sensitivity detection for demanding applications, including the characterization of bioplastics, synthetic polymers and protein assays. The device works on the same wavelength as multi-angle light-scattering (MALS) and strained-layer superlattice (SLS) detectors, and is similar in terms of total cell volume. The AYE detector enables the determination of the absolute concentration, as well as the total mass balance of a sample. The detector operates at room temperatures, up to 80°C. The machine can be configured for either horizontal or vertical operation, enabling users to optimize benchspace. Hall 4.1, Stand K74 — *Testa Analytical Solutions e.K., Berlin, Germany*
www.testa-analytical.com

New heat exchangers for enhanced safety

The K°BLOC is a fully welded plate heat exchanger (photo) that works across a broad range of liquids, temperatures and pressures. K°BLOC units are well-suited for liquid-liquid, condensation and evaporation applications in the chemicals, petrochemical, petroleum refining and oil-and-gas sectors, as well as applications handling pulp, vegetable oil, amines and other process media. The heat exchanger's plate pack provides durability for safer operations, and the exchanger's setup makes it easy to maintain and inspect. This company has also debuted the Double Safety shell-and-tube heat exchanger, which can be used for heat recovery from transformers, or for the recooling of gear and turbine oil, as well as for fuel-gas preheating and compressor cooling. The Double Safety exchanger is suitable for high-pressure applications up to 600 bars. Hall 4.0, Stand B68 — *Kelvion Holding GmbH, Bochum, Germany*
www.kelvion.com

A modular sterility test isolator with many integrated functions

The Stiso sterility test isolator (photo) is used for aseptic and aseptic-toxic products. Its modular design enables flexibility and quick installation. An integrated glove-testing system is included in the human-machine interface (HMI). The Stiso system is said to achieve extremely short cycle times during contamination due to its catalytic conversion capabilities and the built-in DECOjet technology developed by this company. The isolator also features hydrogen peroxide (H_2O_2) flash evaporation technology, which reduces maintenance requirements. In addition to the DECOjet technology, the company also offers the DECOpulse system, which is faster and creates less droplets than typical dispersion systems. Hall 3.0, Stand A73 — *Metall+Plastic GmbH, Radolfzell-Stahringen, Germany*
www.metall-plastic.com

Software dedicated to the details of heat exchangers

This company offers software solutions aimed at advancing research, design and training associated with

heat exchangers. Software solutions such as Xchanger Suite offer advanced thermal process design and simulation. SmartPM simulates complex networks of shell-and-tube heat exchangers to help engineers and plant operators manage fouling. Exchanger Optimizer evaluates the design of heat-exchanger systems to minimize the total installed cost. Customized software and other contract services are also available. Hall 4.0, Stand A62 — *Heat Transfer Research, Inc. (HTRI), Navasota, Tex.*
www.htri.net

New visualization technology for batch operations

The Experion Batch control technology (photo) uses patent-pending visualization technology to provide batch automation processes with the benefits of distributed control capability. This approach provides operators with insights into upcoming events or potential delays, which make it easier for them to conduct multiple tasks, take appropriate actions sooner and adjust next steps accordingly. It also makes operations less critically dependent on individual operator experience, which will help manufacturers overcome skill gaps. Experion Batch also allows plants to easily and quickly transition from recipe testing to execution while reducing testing and validation efforts, and it is aligned with international batch standards ISA S88 and IEC 61512-1. Hall 11.0, Stand C37 — *Honeywell Process Solutions, Houston*
www.honeywellprocess.com

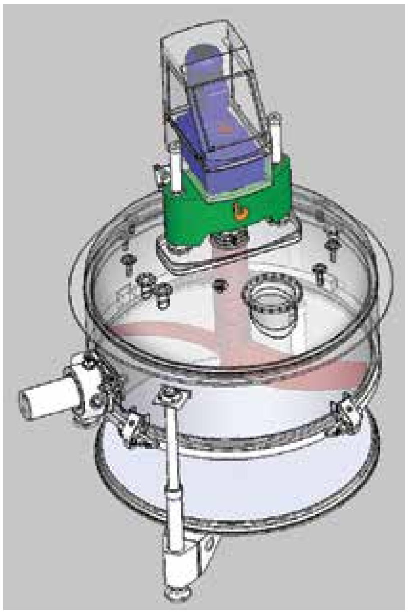
Honeywell Process Solutions

Achieve advanced NMR studies with this benchtop machine

The Spinsolve 80 benchtop nuclear magnetic resonance (NMR) spectrometer (photo) features an extremely high field strength of 80 MHz, a multi-nuclear probe and 5-mm standard NMR tubes to perform advanced spectroscopy methods for many applications, including reaction completion checks, identification, structure elucidation, quantification, purity measurements, online reaction monitoring and quality control. The system requires no sample spinning or cryogen refills. Since users

Magritek

E. Bachiller B.



Optima Pharma

Vaisala

MECO Ireland

can deploy the NMR within their own laboratory, there is no need to wait for results from external providers or transport samples. There is no superconducting magnet on Spinsolve machines, and the magnetic field is completely enclosed, making it safe to install alongside other laboratory analytical instruments, according to the manufacturer. Hall 9.2, Stand A32 — *Magritek GmbH, Aachen, Germany*
www.magritek.com

All-in-one filtration and vacuum drying

The FNB line of Nutsche pressure filters and vacuum dryers (photo) is designed to perform extraction, filtration, pressing, washing, dissolution, bleaching, deodorizing and vacuum drying, all in the same unit without product transfer. The pressure filter features batch-wise operation with a reversible agitator that is variable in height to adapt to many applications, including mixing, cake preparation, purification, scraping, distribution, smoothing, removing and unloading. The dryer is completely heated, including the agitator and bottom. The system boasts reduced opening and closing times and simplified cleaning with an easily exchangeable filtering cloth. The system can handle operating temperatures up to 200°C and pressures up to 3 bars, with an option to increase pressures up to 10 bars. Filters are offered in several materials, including textiles, metal, multilayer (sintered) or ceramic. Hall 5.0, Stand C32 — *E. Bachiller B., S.A., Barcelona, Spain*
www.bachiller.com

These packaging machines can handle many types of containers

This company's Multiuse series of packaging equipment (photo) is proficient in processing different primary packaging materials, including vials, syringes and cartridges. Minimal space is required, since the basic machine does not have to be exchanged to handle different applications or processes. Users will also save time due to an adjustable transport system, and a variety of technologies are available to help minimize product loss. Other beneficial features include optional re-dosing functionality, short hose lines, weigh-dosing, re-capping and more. The Multiuse series is especially well-suited for producers of small quantities of pharmaceutical products, since it is flexible enough to process small batch sizes and different container types while still maintaining high levels of performance for product quality and safety, says the company. Hall 3.0, Stand A73 — *Optima Pharma GmbH, Schwäbisch Hall, Germany*
www.optima-packaging.com/pharma

A new line of probes for high-humidity applications

The new Humicap series of probes (photo), part of this company's Indigo product family, includes the humidity probes HMP4, HMP5, HMP7 and HMP8, as well as the temperature probe TMP1. The probes are easily interchangeable, which minimizes downtime associated with maintenance and calibration. All probes also feature chemical-purge and sensor-heating capabilities. All HMP probes are equipped with this company's new Humicap R2 composite sensor, which provides resistance to corrosion in acidic environments. All HMP probes are also resistant to dust and most chemicals, and their smooth surface is easy to clean. The probes are designed for applications with constant high humidity or rapid changes in humidity, including drying and test chambers, combustion air, humidifiers and meteorological measurements where measurement performance and chemical tolerance are essential. Hall 11.1, Stand C51 — *Vaisala Oyj, Helsinki, Finland*
www.vaisala.com

Multifunctional skid-mounted water-treatment system

The Masterpak (photo) is a modular, prepackaged purified-water production system that incorporates pretreatment, reverse osmosis and electrodeionzation onto a single skid. Also included are integrated control systems and an optional complete-validation package. The Mastepak can be customized to users' requirements, and seven different Masterpak models are available in capacities ranging from 1 to 68 gal/min (4 to 257 L/min). A feedwater PID loop allows for fluctuations in feedwater pressure and temperature. A

backwashable carbon filter eliminates channeling and allows for the removal of dead microorganisms after sanitization. The system's variable-frequency-drive pump enables unit operation, chemical cleaning and hot-water sanitization. The unit can continue to operate when no water is being drawn from the system, due to its recirculation mode. Hall 6.1, Stand D70 — *MECO Ireland Ltd., Limerick, Ireland*
www.meco.com

High pumping capacity combined with minimal wear


Vogelsang

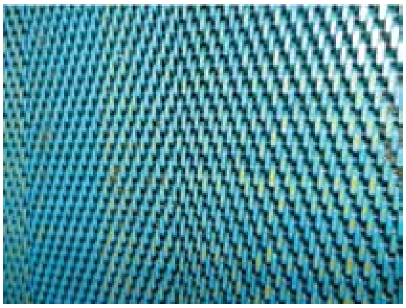
IQ series rotary lobe pumps (photo) are designed with variable connections to provide flexible installation options. For maintenance, the pump remains completely screwed into the pipe. The pump chamber consists of one central part, so that the conveying elements are freely accessible in a few easy steps. By simply removing the cover, the inside can be cleaned, foreign matter removed quickly and blockages cleared. There are only a few spare parts, which reduces the time and cost of replacing worn-out parts. The gearbox housing features an integrated liquid buffer, which ensures improved dry-running protection and a high suction capacity. The IQ pump delivers up to 154 m^3/h of flow at a pressure of up to 7 bars. Hall 8.0, Stand F64 — *Vogelsang GmbH & Co. KG, Essen/Oldenburg, Germany*
www.vogelsang.info

A system for precise label coding and printing


Atlantic Zeiser

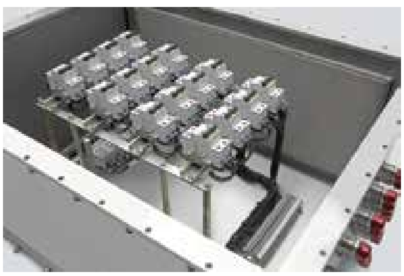
The Digiline Label – Offline system (photo) for central late-stage printing and serialization of flat labels from roll to roll provides consistent and durable printing quality and the possibility to serialize labels with maximum process safety. The system prints at high speeds of up to 60 m/min on different label materials, such as paper, polypropylene, polyethylene terephthalate and polyvinyl chloride, which are lightfast and resistant against wear and alcohol-based solvents. The high-resolution inspection camera can be easily set up over an intuitive HMI and allows users to check content and on-demand quality of text and code elements. Digiline Label – Offline is available with the optional Unique

Georg Fischer Piping Systems



GKD

Endress+Hauser



R. Stahl Schaltgeräte

Code Software (UCS), with which the production of labels with double serial numbers is practically impossible, even after planned or hazardous interruptions in production. At the same time, an almost infinite number of code ranges can be administered, and the reporting and forwarding of serialization data is an integral part of the software. Hall 3.1, Stand B11 — *Atlantic Zeiser GmbH, Emmingen-Liptingen, Germany*
www.atlanticzeiser.com

This welding machine is cleanroom compatible

The IR-315 A infrared welding machine (photo) and the associated worktable are cleanroom compatible. The heating and joining processes are completely automated, and the clamping carriage moves independently. This minimizes application errors and ensures the quality of the connection. Individually adjustable planing dimensions on both sides enable precise, millimeter-accurate production and high flexibility. The active cooling system uses filtered air, and is integrated into the clamping element. It reduces the cooling time by up to 30%, says the company. The IR-315 A supports interactive operation through a graphical user interface. The ergonomically adjustable 12.1-in. touchscreen offers multilingual instructions and video-assisted process control. An integrated video camera documents preparation and handling methods. Hall 8.0, Stand E64 — *Georg Fischer Piping Systems, Schaffhausen, Switzerland*
www.gfps.com/ir-315-a

Specialized belts for dewatering processes

This company's Belt 1003 model of filter belt is designed for dewatering applications in process water treatment, as well as the production of paper and pectin. The Belt 1003 achieves high transverse stability and particle retention. The belts come standard with an integrated wear indicator to provide greater assistance in determining mechanical abrasion. A contrasting colored core (photo) in the woven polyester monofilament provides an early visible indication of the degree of process-based wear or incorrect belt adjustment after loading the belt. This makes it possible to plan belt changes and promptly implement any necessary corrections. For applications with fibrous sludges, which are less capable of flowing, such as those typically encountered in the paper industry, model 1003 belts are also now available in a spiral configuration, which provides improved stability. Hall 5.0, Stand C62 — *GKD – Gebr. Kufferath AG, Düren, Germany*
www.gkd.de

This hygienic thermometer is equipped with self-calibration

The new iTherm TrustSens hygienic thermometer (photo) is designed for the life sciences, biotechnology and food-and-beverage industries. For users who require full compliance with FDA and GMP regulations, iTherm TrustSens offers a high degree of process reliability and system availability thanks to permanent inline self-calibration, thus eliminating the risk of nonconformities during production and avoiding production downtime. The device features a measuring range of –40 to 160°C (–40 to 320°F). Also, there are more than 50 sterile and hygienic process connections available, including thread, clamp, DIN11851 and more. Hall 11.1, Stand C27 — *Endress+Hauser AG, Reinach, Switzerland*
www.endress.com

Explosion-proof enclosure system with a smaller footprint

The EXpressure technology (photo) can safely dissipate explosion pressure in control boxes, power distribution boards and other enclosures via flow channels in multi-layer stainless-steel wire cloths. The controlled gas flow and heat absorption through special wire-cloth elements reduce the internal pressure increase that occurs after an explosion in the enclosure by several orders of magnitude compared to conventional Ex d enclosures, says the company. If explosion pressure increases of 7 to 12 bars have to be contained in a conventional flameproof enclosure, the maximum inner pressure in an EXpressure enclosure is less than 1 bar. While some enclosures may require a wall thickness of 10–20 mm, EXpressure enclosures achieve comparable

protection with walls that are approximately 3 mm thick. Hall 11.1, Stand C45 — *R. Stahl Schaltgeräte GmbH, Waldenburg, Germany*
www.r-stahl.com

New communication protocol available for these flowmeters

Profinet I/O industrial Ethernet communication is now available for this company's electromagnetic flowmeters and Coriolis mass flowmeters (photo). This includes all compact and field versions of the Optiflux x300 electromagnetic flowmeters and Optimass x400 Coriolis flowmeters. With Profinet I/O, all measuring, process and diagnostic information from the meters is available in realtime via a single communication channel, allowing for direct and convenient integration of new meters and direct identification of defective devices, as well as bidirectional communication and parameter setting. Also, the Optimass portfolio of mass flowmeters has been supplemented with large line sizes up to 16 in. (DN400). With this expansion, the company now offers a complete Coriolis portfolio for flowrates from 0.3 kg/h up to 4,600 ton/h. Hall 11.1, Stand A3 — *Krohne Messtechnik GmbH, Duisburg, Germany*
www.krohne.com

These double block-and-bleed valves are certified for fire safety

The Taurus Series of double block-and-bleed valves (photo) provide a double-isolation function with a twin-ball design. The valves are available from 1 to 6 in. full-bore (8-in. reduced-bore). The ball valves have an anti-blowout stem and an anti-static design, and are fire-safety tested and certified according to API 607 and ISO 10497. Where necessary, polyether ether ketone (PEEK) is available as a seat material and Duplex as a ball material. Stems are generally made of XM-19, an austenitic stainless-steel grade that has a greater corrosion resistance and higher yield strength than 316 stainless steel. All other trim materials and all non-wetted parts are provided in 316 stainless steel, making the valves

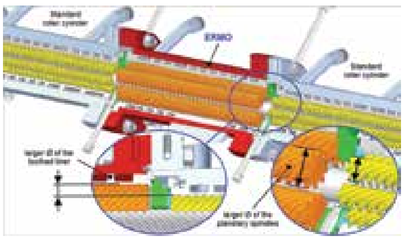
Krohne Messtechnik

Armaturenfabrik Franz Schneider

25430

Bürkert Fluid Control Systems

LEWA



Entex Rust & Mitschke

Allweiler

suitable for installation in corrosive environments. Hall 8.0, Stand A85 — *Armaturenfabrik Franz Schneider (A.S. Schneider) GmbH + Co. KG, Nordheim, Germany*
www.as-schneider.com

Valve positioners with an industrial Ethernet interface

This company has introduced new positioners and controllers of the Type 8692/8693 + 8792/8793 product line (photo). The new positioners and controllers support EtherNet/IP, Profinet and Modbus communication protocols. The protocols enable extensive diagnostics functions, including monitoring, limit value definition of operating parameters and messages in accordance with Namur NE107. The integrated two-port switch allows for star, line and ring topologies and, facilitates failsafe communication right up to the valve. All integrated devices can be parameterized and configured using Communicator, the standard software tool. The new positioners have been optimized for combination with this company's process-control systems and also enable an array of combinations with all control valve types, including those from third-party manufacturers. Hall 11.1, Stand E62 — *Bürkert Fluid Control Systems, Ingelfingen, Germany*
www.burkert.com

New capacity added to this series of diaphragm pumps

The new LDZ drive unit (photo) is now available for this company's Ecoflow series of diaphragm metering pumps. The LDZ unit is designed for a hydraulic output of 15 kW and is intended to close the gap between the LDG (6 kW) and the LDH (20 kW) models. The LDZ can be used as a single or multiplex drive unit, and thanks to its modularized system, can be tailored to users' needs. For instance, wetted materials and process valves can be adapted specifically to the pumped fluid as needed. Furthermore, implementing a heating or cooling jacket or a remote head solution is possible at extreme temperatures. Among the five pump-head types, there are also adaptations available for use in the food and pharmaceutical industries. Hall 8.0, Stand D62 — *LEWA GmbH, Leonberg, Germany*
www.lewa.com

A new degassing reaction module for extruders

The ERMO degassing reaction module (photo) is now available for this company's modular planetary roller extruders. The ERMO can be installed at any point of the process section as a replacement for a standard roller cylinder. The standard planetary spindles are replaced by the larger ERMO planetary spindles and the intermediate rings connected upstream and downstream are replaced by appropriately adapted intermediate rings. The larger diameters of the toothed liner and planetary spindles provide a significantly larger process volume compared to the standard roller cylinder of the same size. The original central spindle can remain and no further modifications of the existing extruder are necessary. Depending on the process requirements, several ERMOs can be installed in line or at individual positions of an extruder processing section. There are various supplementary options, such as side-feeders or additional injection and degassing openings. Hall 4.0, Stand D8 — *Entex Rust & Mitschke GmbH, Bochum, Germany*
www.entex.de

Intelligent, expandable system for pump condition monitoring

The IN-1000 intelligent condition-monitoring system (photo) is now available with the necessary certifications for operation in ATEX Zone 2, Class 1, Div. 2. The system is designed specifically for use with this company's pumps that are used in operationally critical and environmentally sensitive applications. The IN-1000 can be used for a wide range of condition-monitoring applications, from simple, single-pump installations to complex, multi-pump systems, says the company. As a result, maintenance and repairs can be planned in advance, there is no unplanned production downtime and maintenance intervals can be extended. The system can monitor temperature, leaks and vibrations, and may also be expanded with standard industrial sensors to monitor other parameters, such as pressure. It can be added to new pumps or retrofitted to existing pumps. Hall 8.0, Stand D63 — *Allweiler GmbH, Radolfzell, Germany*
www.allweiler.com

VEGA Grieshaber

Level measurement for all bulk solids with 80-GHz radar sensors

In industrial processes, sensors have to deliver reliable measuring results for a wide variety of bulk materials, such as granulates, mineral slurries or suspensions containing solids. The 80-GHz radar sensor Vegapuls 69 (photo) offers precision for reliable and flexible processes. Stable, accurate measurement is ensured even with poorly reflecting media, dust or false echoes from installations in the silo, says the company. The device is suitable for leavel measurement in very high silos, large bunkers and segmented vessels. The Vegapuls 69 can be equipped with an encapsulated plastic antenna or a lens antenna integrated in the metal flange, which enables flexible adaptation to different applications. Hall 11.1, Stand C63 — *VEGA Grieshaber KG, Schiltach, Germany*

www.vega.com

Müller Systems & Handling

Single-use containment valves prevent cross-contamination

This company now offers a fully automated single-use variant of its MCV model of containment valve (photo). The new model, known as MCV-LW, is a lightweight split butterfly valve constructed of a performance polymer material. The levers for locking the valve and actuating it can be changed over from those for manual operation and those for pneumatic actuation. The pneumatic actuators can be controlled via a programmable logic controller (PLC). The MCV-LW is designed for GMP-compliant manufacturing where powders and granular materials are processed. Its suitability for single-use operation reduces the risk of cross contamination. Hall 3.1, Stand A75 — *Müller Systems & Handling GmbH, Rheinfelden, Germany*

www.mueller-group.com

Japan Steel Works

Use this compact extruder for laboratory and R&D applications

The TEX25αIII laboratory extruder (photo) is a compact co-rotating twin-screw extruder that is designed for product development of various compounds and masterbatches in engineering and high-performance thermoplastics. It has a diameter of just 26.5 mm. The company has developed a specialized TEX25αIII model targeted at reactive and devolatization processes. This particular model uses three long vacuum-vent barrels for preventing entrainment at the vacuum vent zone during devolatilization. The laboratory model is the smallest of the TEX25αIII product family, which includes models with diameters up to 129.5 mm. The TEX25αIII design allows the laboratory extruder to process material in a wide range of shapes and physical forms, including liquids, powders, pellets, flakes, chips, regrind and so on. This makes the compounder suitable for research and development projects that require frequent material and process changes, as the extruder's cartridge heaters and barrel-clamping mechanism enable easy and rapid barrel-section block changes. Hall 5.1, Stand D47 — *Japan Steel Works, Ltd. (JSW), Tokyo*

www.jsw.co.jp

i-Safe Mobile

A wearable tablet for explosive environments

The HMT-1Z1 (photo) is said to be the world's first completely hands-free, head-mounted tablet for work in Zone 1/21 hazardous areas. The HMT-1Z1 runs on the Android 6.0.1 operating system, and the apps and functions are activated and controlled using speech. Remote video support allows mobile workers to receive help from the helpdesk, view technical documentation, download data, access maintenance instructions and sketches or record inspection work. The HMT-1Z1 can be integrated into safety helmets or attached to shock caps, and can be used with safety or correction goggles. The data are displayed on an integrated screen with a viewing angle of 20 deg to ensure interference-free operation in backlight or strong sunlight. The voice guidance works precisely even in noisy environments. In addition, an integrated scanner in the camera helps to capture data. The HMT-1Z1 supports the use of powerful software applications for remote mentor video calls, document navigation, digital workflow, mobile forms, industrial IoT data visualization and more. Hall 11.1, Stand A25 — *i-Safe Mobile GmbH, Lauda-Königshofen, Germany*

www.isafe-mobile.com ■

Mary Page Bailey and Gerald Ondrey

Exploring the current status of industry 4.0

ANDRITZ Group provides solutions for Flexible Production

How can organizations become more flexible, more specialized, faster? How can automation be applied to existing plants to deliver concrete results but with minimal downtime?

The answers to these questions are not just around the corner – **ANDRITZ Group** customers are already reaping the dividends from them. Digital networking for industrial production is based on the three pillars of technology: Big Data, Smart Sensors, and Augmented Reality.

The Metris OPP (Optimization of Process Performance) system, for example, contains a series of digitally supported tools to enhance industrial processes. ANDRITZ is serving clients as far afield as Brazil, Europe and the USA with this technology and in 2017 alone was able to achieve a total net benefit in excess of 30 million euros for customers with an ANDRITZ OPP contract.

And yet it's important to remember that digitalization is an evolutionary development for this industry not a revolutionary one. Automation and remote maintenance have been around for decades, but now they are getting much smarter much faster. ANDRITZ sees these technologies as an enabler and driver but ensures that the focus never strays from concrete customer benefits and how to convert data into money. **www.andritz.com/separation**

The chemistry is right

Single-source provider for filling, palletising and packaging technologies

BEUMER Group develops complete packaging lines from one source for pharmaceutical and chemical companies. This means that the customer can omit or minimise interfaces and only needs one point of contact. What is special is that the system supplier dimensions the performance of the single machines and components as well as the high-level control in an optimum way. Thus the customer receives a complete line with optimum throughput.

The BEUMER fillpac FFS form fill seal system forms a ready-made tubular PE film into a bag and fills it with the customer's technical plastics like PE, PP, PA or PS pellets. Reliable and gentle filling is also possible for salts or fertilisers. The pellets are then weighed before the filling process. For this, the BEUMER fillpac FFS is equipped with an electronic calibration-capable weighing unit. Then the system seals the bags with a weight of up to 25 kg. BEUMER Group offers the BEUMER fillpac FFS both for the high-capacity area of up to 2,600 bags per hour and for low throughputs up to 1,800 or 2,500 bags per hour. Depending on the customer requirements the suitable machine performance class can be selected from the extended product range.

BEUMER Group offers the product family of the BEUMER fillpac FFS in various performance ranges.

BEUMER at the Achema: hall 3.0, booth F50

www.beumergroup.com

New: All-ceramic chemical pump

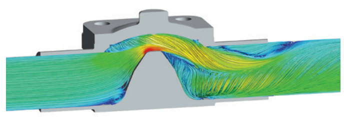
Thriving in difficult applications: The dry-running, self-regulating and hermetically-sealed all-ceramic pump K-MPCV-AN is perfect for pumping extreme media which can be hot, corrosive and abrasive, like ammonium nitrate with dolomite, iron oxide and other slurries. With permanently dry-running magnetic coupling and roller bearings, the vertical pump operates without bearings in pumping liquid. The shaft gap seal concept is based on the complete hydrodynamic relief of the bearing and seal unit. The K-MPCV-AN works with unique control characteristics, adapting automatically to variable feed rates. Extremely reliable and low-maintenance, the hermetically-sealed all-ceramic pump K-MPCV-AN is economical, with little monitoring and generous maintenance intervals.

Visitors can experience the three functional models of the special centrifugal pumps at ACHEMA. For the first time, the fast, pressureless and complete unloading of a tanker truck will be shown with a miniature glass railway tank car: Hall 8, Stand C 1

www.bungartz.de

Clever design increases diaphragm durability

Optimised design and perfect interaction of components make diaphragm valves by **Bürkert** exceptionally durable, maintenance-friendly and hygienic.



The optimised forged body geometry is beneficial both for diaphragm life times and for higher flow coefficients.

Bürkert diaphragm valves can be assembled from a wide range of bodies, diaphragms and actuators to suit every application. The valve interfaces and forged bodies have now been further improved in terms of the design and interaction of individual components.

With the new Tube Valve Body, Bürkert has already developed an innovative body, whose lightweight design saves energy during the heating phase and time during the cooling process. This makes processes sustainable and more productive. Now, the geometry of the 2-way forged bodies has also been optimised. A smooth edge radius on the body reduces the stress on the diaphragms, making them last up to 50% longer.

The design modification also improved the forged body from a hygienic perspective. An axial sealing lip on the diaphragm increases the compression. Leak-tightness has been improved in this way to prevent the ingress of media or foreign particles. As a result, the fluid is better protected against contamination.

Bürkert Fluid Control Systems, ACHEMA 2018 Hall 11.1, Booth E62

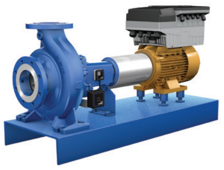
www.burkert.com/DiaphragmValves

New system puts pumps into the Internet of Things

At this year's ACHEMA, **KSB** is presenting a new pump monitoring system called KSB Guard. Networked vibration and temperature sensors fitted directly to the pump make availability at plant level transparent for the first time. The system ensures that changes in the operating behaviour of the machine are detected at an early stage, and maintenance work can be better planned, without having to be on site with the pump.

Unlike previous systems, KSB Guard is ideally suited for retrofitting. The sensor unit is attached to the bearing bracket or the drive lantern of the pump using a magnet and adhesive, and can be mounted during operation, with no need for changes to the machine. A battery unit, which is also supplied, provides self-sufficient power supply.

The data, which is captured hourly, is transferred directly and wirelessly in encrypted form to the KSB Cloud via a gateway for processing. Users can query the status data of all monitored pumps at any time and from any location using their mobile phone, a tablet or a PC, without having to be on site. For maximum coverage in the field, KSB Guard establishes a mesh network within the monitored pumps, thereby minimising the number of gateways required.



The new KSB Guard pump monitoring system enables existing pumps to be connected to the Internet of Things in just a few minutes.

www.ksb.com

LEWA looks back on positive business development over the last three years

At this year's Achema LEWA presents the new Ecoflow LDZ as a triplex unit featuring three different pump heads.

The past three years following Achema 2015 were a period characterized by several challenges for **LEWA GmbH**. The pump manufacturer was awarded contracts on many calls for tenders, both in the process industry and in the pharmaceutical sector—all while the market atmosphere worsened, most notably in the oil and gas sector. Despite the lack of industry growth, the company continued to make long-term investments and went ahead with an extensive expansion at the Leonberg factory site. LEWA plans to maintain this course for 2018. At this year's Achema LEWA defines three exhibition key topics: The first is a new performance rating within the successful Ecoflow pump series. The Ecoflow LDZ will be presented as a triplex unit featuring three different pump heads, serving as a typical example of how versatile LEWA pumps are. The second key topic involves various solutions and an application example from Industry 4.0, while the third focuses on the new NIKKISO centrifugal canned motor pump models, manufactured in accordance with DIN EN ISO 2858.

www.lewa.com

Chemical Feed Systems for Municipal, Industrial, OEM

Complete in-house engineering and production

For over 80 years, **Lutz-JESCO America Corp.** has manufactured and sold chemical feed technology and related equipment throughout North and South America.

As one of the first metering pump manufacturers in the Americas to offer complete chemical feed systems, we have established ourselves over the past decade as a chemical feed system specialist.

By consistently meeting highest standards relative to the quality of our equipment, our customer service and on-time delivery, and due to our flexible way of conducting business, we have achieved an outstanding position within the chemical feed technology industry.

Our company stands for industrial, municipal and OEM chemical feed solutions of highest quality, reliability and safety. We strive for a maximum in customer satisfaction by being a customer oriented organization throughout the entire sales and after sales cycle.

www.lutzjescoamerica.com
www.chemicalfeedsystems.com

Safest solution for highest vacuum requirements in chemical industry:

Magnetically coupled and ATEX certified Roots pumps

Pfeiffer Vacuum introduces ATEX certified Roots pumps with a magnetic coupling to the vacuum market. The tried and tested Roots pumps principle was further developed for this certification and named OktaLine ATEX. Vacuum pumps in the OktaLine ATEX series are ideal for processes in explosive areas or for evacuating explosive gases according to the ATEX directive (2014/34/EU): in chemical and process technology applications, industrial applications, coating, the semiconductor industry and research & development. Depending on the application, clients can choose between equipment category 2 and 3. All pumps are suitable for temperature class T3.

OktaLine ATEX by Pfeiffer Vacuum

The magnetic coupling was a major contribution to the existing tried and tested Roots pumps. These hermetically sealed pumps have very low leakage rates of less than $1x10^{-6}$ Pa m^3/s.

www.pfeiffer-vacuum.com

Pressure relief solutions

A graphite rupture disc that is setting new standards in terms of durability - also with regard to the application temperature and a rupture signalling device that is unbeatable in terms of process leak-tightness: these are this year's ACHEMA highlights from the world leading rupture disc manufacturer **REMBE**.

NIMU non-invasive monitoring unit

A signal indicator is attached to the rupture disc during the manufacturing process. The actual sensor is screwed into a blind tapping in the rupture disc holder, where it monitors the position of the signal indicator on the rupture disc. The absence of cable glands (required for the holder tappings for conventional signalling cables) means that the cable glands used cannot become porous, thus preventing an escape of the process media additionally, no signalling cables have to be routed again to the respective switching box after a pressure relief.

GRX - cool and hot

REMBE graphite rupture disc GRX

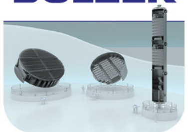
If the process temperature is between -180°C and 1,500°C, the process involves corrosive media, and the rupture disc must already respond at a relatively low pressure, then the REMBE graphite rupture disc GRX is ideally suited to relieve the pressure. Thanks to a specially developed coating, the GRX does not require polymeric sealants, and is able to withstand the aforementioned demanding process conditions, while still guaranteeing absolute leak-tightness.

Meet the REMBE experts at hall 9.1, stand C4 **www.rembe.de**

Virtual reality experience at ACHEMA 2018

Sulzer Chemtech offers virtual reality (VR) and augmented reality (AR) tours through processing equipment and plants at ACHEMA 2018.

SULZER



Sulzer Chemtech, the leader in separation and mixing technology, has created a virtual environment for ACHEMA attendees. Thanks to a free-to-download VR app, they will be able to experience an immersive, realistic, 360° insight into Sulzer Chemtech's latest developments in separation process equipment. Visitors will be able to examine a range of column internals.

The app, which can be used on smartphones with VR glasses, will allow the visitors at the indoor fair to walk among Sulzer Chemtech's pieces of equipment, which can reach heights of over 50 meters, interact and access relevant information of the products, in the form of text, videos and pictures.

Sulzer Chemtech will also present a VR experience of a complete process plant and an AR application for a hands-on experience of a chemical process plant and how Sulzer Chemtech's equipment fits into it.

Visit Sulzer Chemtech on stand D48, Hall 4.0 at ACHEMA 2018. June 11-15, 2018 – Messe Frankfurt, Frankfurt am Main, Germany.

www.sulzer.com

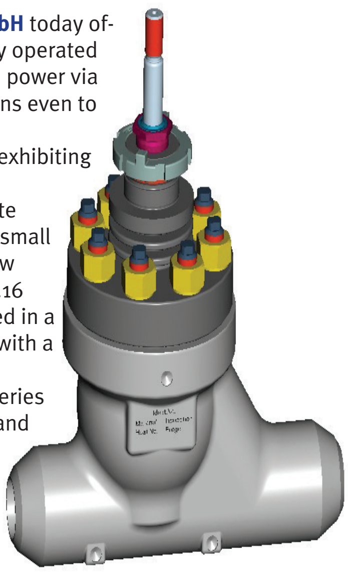
Dynamic range makes the difference – level measurement with 80-GHz radar accurately detects the level

If the key to greater plant availability is precise control, the key to precise control is high-performance measurement technology. It must be extremely robust, have minimum measuring tolerances and be flexible and easily integrable into any system. The different reflective properties of different media have been a real challenge for radar up to now, but the 80-GHz radar **VEGAPULS** sensors have no problem in this area, delivering a convincing performance with reliable measured values. It's the unique dynamic range of VEGA instruments together with their strong signal focusing that makes the difference here.

As a result – thanks to VEGAs optimized dynamics and a high signal frequency of 80 GHz – the dielectric constant of the medium is no longer a limiting factor in liquid applications. And in the case of bulk solids with good reflective properties, such as fertilizers or salts, measurement certainty and reliability get even better with 80-GHz radar. But even bulk solids with poor reflective properties, including plastic powder or light colour pigments, can be measured, and that with considerably higher quality than ever before.

www.vega.com/radar

100 Years of Innovation



Founded in 1917, **ARCA Regler GmbH** today offers pneumatically and electrically operated control valves for all industries, from power via chemical & petrochemical applications even to food and beverage.

At ACHEMA, ARCA Regler will be exhibiting the following new technologies.

Firstly, its Series 8C/6H rotary gate valve with graven characteristics for small flow coefficients. Microflow rated flow coefficients (ranging from rated Cv 1.16 down to rated Cv 0.01) can be realised in a standard globe valve housing, even with a rangeability of 50:1.

The company will also show its Series 190 dye-forged control valve (globe and angle style) with butt-welded connections, designed according to DIN EN 12627 and ASME/ANSI B16.25. This valve is available in nominal diameters, ranging from DN 25 to DN 65 (ANSI 1 – 2.5 in.), with ratings of PN 160 – PN 400 (ANSI Class 900 – 2500)

Finally, control valves with multi-stage throttling cages, individually designed to fit to any given plant characteristics and produced by additive manufacturing, will also be exhibited.

Hall 8.0, Stand H93

www.arca-valve.com

Intelligent valve automation

AUMA's compact electric actuator ranges offer precise, robust and reliable flow control for chemical, food, and other industries.

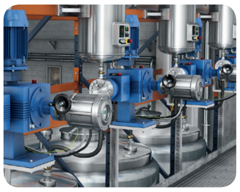
Electric actuator manufacturer **AUMA** is showcasing the latest advances in valve actuation at this year's ACHEMA. The new SDL linear actuators are ideally suited for demanding temperature control systems, for example preheating and cooling systems, and fluid metering systems.

The smart actuators are equipped with variable-speed motors that provide soft starts and stops, ensuring gentle treatment of mechanical components. Variable-speed operating profiles help to avoid critical pressure surges and cavitation. Parameters can be set via software, and both Modbus RTU and Profibus DP interfaces are available.

The new SDL actuators complement AUMA's wide range of compact actuators, all designed for high precision process control even under harsh industrial environments. Linear actuators cover thrusts of 0.6 – 25 kN and strokes of 35 – 300 mm. Part-turn actuators offer torques of 25 – 1,000 Nm. Globe valve actuators offer torques of 10 – 100 Nm, with strokes from 60 – 70 mm.

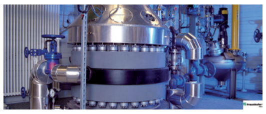
ACHEMA hall 8.0, C23

www.auma.com



AUMA SDL linear actuators provide high positioning accuracy for demanding metering and temperature control applications.

High Performance Technology for Hydrogenation



And Other Reactions Limited by Mass and Heat Transfer

The Challenge

The hydrogenation reaction is highly exothermic and very mass transfer resistant.

The Solution

The **BIAZZI**'s High Performance Reactor System (BHPR) is characterised by a high capability for heat removal and high gas-liquid mass transfer, as well as high internal gas recirculation.

The advantages

- High productivity
- High quality of the products
- Highest Safety standards
- Full performance guarantees
- Optimised OPEX and CAPEX
- Scale-up in shortest time
- Minimum maintenance needed

Applications for the chemical Industry

The BHPR is used for Gas/Liquid reactions (e.g. Hydrogenation, Oxidation, Carbonylation, Amination, etc.).

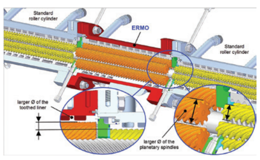
Scale-up

BIAZZI scales up laboratory test results directly to any size of industrial plants up to 50 m³ and gives performance guarantees covering capacity, product yield & quality, etc. for industrial plants built in the shortest time.

Modular system

BIAZZI offers from basic engineering and the delivery of Key-Equipment up to SKID mounted units. **www.biazzi.com**

New generation of degassing reaction module



ERMO degassing reaction module enhances efficiency and versatility of **ENTEX** planetary roller extruder.

The patented addition to the modular ENTEX construction system offers a significantly larger process space volume compared to the standard roller cylinder of the same size. This is due to the increased internal diameter of the toothed liner and planetary spindles with a larger diameter.

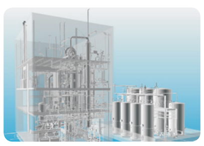
Developed for degassing applications, where free large-scale process surfaces and generously dimensioned flow cross-sections are decisive, ERMO maximizes these aspects without significantly changing the size of the extruder.

ERMO can be installed at any point of the process section as a replacement for a standard roller cylinder. The standard planetary spindles are replaced by the larger ERMO planetary spindles and the intermediate rings connected upstream and downstream are replaced by appropriately adapted intermediate rings. Due to the slightly larger outer diameter of the ERMO cylinder, the heat protection jacket is also replaced. The original central spindle can remain and no further modifications of the existing extruder are necessary.

Like all other components of the modular ENTEX system, depending on the process requirements, several ERMOs can be installed in line or at individual positions of an extruder processing section. In addition, there are various supplementary options, such as side-feeders or additional injection and degassing openings. **www.entex.de**

Recovery of high-boiling solvents

GEA supplies industrial plants for the separation of compound mixtures by distillation/rectification and stripping.



The production of various synthetic fibers like acrylic fibers, rayon, aramid fibers as well as capillary membranes for medical applications require large amounts of water and solvents.

In the course of the wet spinning process, a high-boiling solvent (e.g. DMAc or NMP) is extracted with water from the fibers. The solvent is highly diluted and contaminated with impurities. A direct reuse is impossible and a disposal of the contaminated solvent is due to ecological and economic aspects not an option. **GEA**'s MVR (mechanical vapor recompression) heated distillation technology enables manufacturers to recover up to 98% of the solvents with high purity, while minimizing energy consumption. Furthermore, the process water needed for the precipitation step is regenerated and can be recirculated.

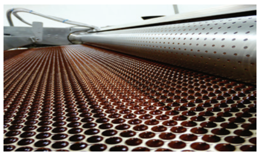
GEA's distillation plants are recognized worldwide for their high thermodynamic efficiencies and high distillate purities achieved. Due to extensive product know-how and expertise in designing multi-stage and MVR heated plant concepts, GEA is able to offer innovative tailor-made and thermally optimized solutions – from product testing and design throughout project execution to start-up, operation of your plant until individual service concepts.

ACHEMA hall 4.0, F46

www.gea.com

IPCO presents the new Rotoform HP

Reliable, high performance processing



IPCO, previously operating as Sandvik Process Systems, is introducing the new Rotoform HP (High Performance). The Rotoform HP rotary depositing system is built on the proven strengths of our Rotoform 4G but brings particular benefits to the challenge of processing of high viscosity products at high volumes.

The key difference between this and our standard 4G model is a significantly larger product distribution channel coupled with an increased outer shell diameter. This enables increased efficiency in terms of even and consistent distribution of the melt across the full width of the steel belt cooler, ensuring maximum pastille uniformity.

This is particularly beneficial in terms of high capacity processing of high viscosity products such as chocolate, but the inherent flexibility of this system means it will handle other viscos materials with high efficiency.

Other improvements incorporated into the development of this model include the innovative and patented feature to influence the product distribution while production. It allows the optimization of the system to achieve maximum possible pastille uniformity.

Reliable, versatile and easy to use, the IPCO Rotoform HP is available on new systems or as a retrofit replacement like all the other IPCO Rotoform systems.

www.ipco.com

i.safe MOBILE presents a world first at ACHEMA 2018

i.safe MOBILE is an innovative specialist for mobile communication devices that guarantee safe use in hazardous areas. The i.safe MOBILE development team incorporates all international standards into product development and is itself a member of corresponding standardization committees. i.safe MOBILE not only develops devices, but also manufactures specially adapted mobile devices for the specific requirements in close cooperation with its customers

At ACHEMA 2018 i.safe MOBILE will present its latest smartphones and mobile phones, tablets and accessories such as multipens - for ATEX zones 1/21 and 2/22. i.safe MOBILE's IS520.1 is an industrial smartphone with the latest technical standards, combining modern design and absolute robustness in one industrial product. The IS320.1 feature phone can be operated both via keys and the touch screen, supports NFC and is equipped with an SOS button and an LED torch, among other things. The 8" tablet IS910.1 is not only extremely robust but can also score with a very durable 6,000 mAh battery. There are also plans to present a world novelty in the field of intrinsically safe communication devices, one can be curious what this will be.

Hall 11.1, Booth A25

www.isafe-mobile.com

Optimized Processing with Müller Emptying Systems

Enclosed Systems ensure low-loss production of viscous media

The economical and low-loss production of valuable pastes, creams and ointments, is a daily task for companies processing viscous products.

Müller's user-friendly container and emptying systems are the solution for this demand. High handling costs can be reduced, problems with stringent hygiene requirements easily be solved, and the product can be transferred nearly loss-free to the filling machine.

Enclosed System for complete emptying of viscous media

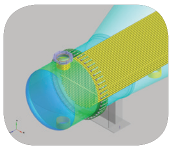
Müller drums manufactured from stainless steel become enclosed systems for the complete media processing. The viscous product is fed into the production line directly from the storage container in three phases: Filling the drum, transportation and storage, drum emptying directly into the filling machine – all done in one drum or container.

The GMP- and FDA-compliant emptying systems by Müller are easy to clean, have small footprints, and are available in different sizes and versions, suitable for a wide spectrum of applications.

More information and detailed consultation:
E-Mail: processing@mueller-group.com
ACHEMA 2018: Hall 3.1 Stand A75

www.muellerprocessing.com

Your PASS to Quick, Effective Piping, Equipment Flow and Stress Analysis



Process plant piping and equipment simulation can be very complex. To consider all appropriate operating conditions, physical phenomena (multiphase flow and surge, nonlinear behavior etc.) and safety codes, special software tools are necessary. Ideally, these should not require users to be simulation experts but enable "regular" engineers to design safe and well performing systems. Fortunately, such software already exists!

PASS: The Piping and equipment Analysis & Sizing Suite offers smart, powerful tools for every engineer and is already in successful use at hundreds of companies.

Wondering how is it possible? No secret ingredients, just the best ones:

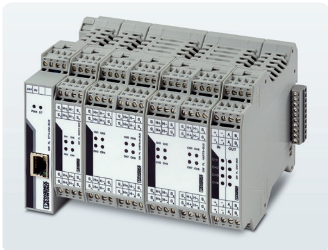
- Best in class modern algorithms – proprietary and from partners all over the world
- Easy to use and friendly Graphical User Interface
- Flexible PASS/CAD integration enabling effective design workflow
- Embedded knowledge, automating standard tasks while freeing-up users for creativity in design
- Online access to professional knowledge and experience
- Quick support and training directly from developers and experts
- Flexible and affordable licensing for all categories of users

See PASS in action at ACHEMA 2018 (Hall 9.2 B17)!

www.passuite.com

Phoenix Contact updates Ethernet HART multiplexer

A firmware update is available for **Phoenix Contact**'s Ethernet HART multiplexer that adds support for the ARCOM protocol, enabling connectivity with Emerson's AMS Device Manager asset management software, which helps avoid unnecessary downtime by providing a window into the health of intelligent field devices.



The multiplexer GW PL ETH provides a simple way to parameterize and monitor field devices on an Ethernet network, and is an up-to-date replacement for widely used RS-485 HART multiplexers. Designed for applications like partial-stroke testing, valve diagnostics, and batch-data transfers, the multiplexer features a HART master on each channel for the fastest possible updates and execution times.

The multiplexer consists of a head station and a variety of HART expansion modules to suit any application need. The modular design allows up to five expansion modules to be connected to a single head station. That makes this a scalable solution for modern, distributed control systems and phased roll-outs. In addition to the new ARCOM support, the multiplexer also supports HART IP, features a CommDTM for integration into an FDT Frame application, and converts HART parameters into Modbus TCP or Profinet.

www.phoenixcontact.com

Pressure Insensitive Mass Flow Controller

EL-FLOW® Prestige, the newest generation of **Bronkhorst** Mass Flow Meters/Controllers for gases, can now be equipped with an on-board pressure sensor. In combination with the "Differential Temperature Balancing" sensor technology and an incorporated gas database with physical properties, the instrument automatically compensates for inlet pressure variations. As a result, the accuracy and control stability will not be affected by these pressure changes. Next to an improved yield of the customer's process, additional components for line pressure control will no longer be required.

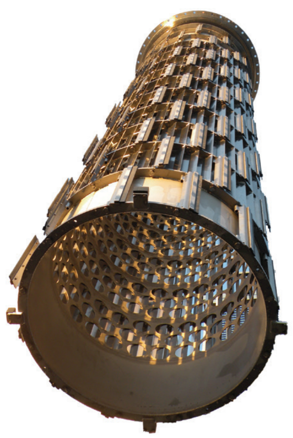
EL-FLOW® Prestige Pressure Insensitive Mass Flow Controller

The Multi Gas / Multi Range functionality of the EL-FLOW® Prestige enables the user to select any of the installed gases and to adjust the measuring range within the boundaries of the device. Also the dynamic behaviour of the mass flow controller can easily be tuned on site, by adjusting the controller speed parameters. These settings can be changed using our free software tools FlowTune™ or FlowPlot™. The last mentioned tool can also be used for device diagnostics or alarm and counter settings.

www.bronkhorst.com

The Truth about BIODIESEL production

Biodiesel nowadays is indispensable. The need is in a continuous climb and the possibilities of applications are constantly expanding. The type of production is still crucial. There are different processes for the production of biodiesel, each has its advantages but also disadvantages, and thus there are also quality differences. **GIG Karasek** Short Path Technology ensures low vaporization and optimized integration into an overall system and is the best solution in terms of quality and energy. In order to conserve resources and the environment and to get the most out of it, the short path technology in the production of biodiesel and these valuable substances, which are suitable for a wide range of applications, are carefully separated and cleaned. Therefore it is possible to produce Biodiesel acc. to EN14214 in the shortest possible time, without long downtimes and with the highest quality.



Hall 5.1 Stand A64 – GIG Karasek GmbH

www.gigkarasek.at

Critical Application? We've Got You Covered!

PSG®, a Dover company, offers a wide range of pumping solutions that solve the most critical chemical application challenges. No matter the application, PSG has a specific solution from proven technologies and brands that you can trust, such as Almatec®, Blackmer®, EnviroGear®, Finder, Mouvex®, Quattroflow™ and Wilden®, among others. PSG is a global leader in the manufacture of pumps, systems and related flow-control solutions for the safe and efficient movement, measurement and control of the most critical and valuable materials. The company's products are manufactured on three continents - North America, Europe and Asia - in state-of-the-art facilities that practice lean manufacturing and are ISO-certified. PSG proudly employs 1,400 team members in 19 global locations and supports more than 1,700 channel partners in more than 100 countries. For additional information on PSG, please go to psgdover.com or visit us at the ACHEMA 2018 show in Hall 8.0 Stands C46 & D37.

www.psgdover.com

Transforming operations at every level through digitalization

The **ABB** Ability platform, an integrated industrial Internet offering with over 280 digital solutions and a cloud infrastructure, has been proven to help companies know more, do more, do better.

Technologies being highlighted by ABB at ACHEMA have helped chemical companies cut costs up to 30% and shorten project schedules by 25%. Visitors to Hall 11.1 Stand A61 and Hall 9.2 Stand D41 will see how ABB's digital solutions turn vast amounts of data into actionable insights which improve performance at device, process, plant and enterprise levels.

Elsewhere ABB experts will be discussing:

- Pharma 4.0 Plug & Produce solution by ABB – 11.06.2018, 15:40, Room: H1.1-Logistics Hotspot
- Orchestration of Modular Process Plants – 12.06.2018,12:00, Room: CMF-Illusion 3
- Novel laser analyzers for measurements and mapping of natural gas leaks while driving– 12.06.2018, 16:00, Room: H11.0- Korall
- Fleet analytics and advanced diagnostics for rotating equipment – 14.06.2018, 15:00, Room: H9.2
- Big data analytics: improving batch operations in chemical plants – 14.06.2018, 15:40, Room: H9.2

www.abb.com/chemical

Supplying the Process Industries with High Performance Vacuum Systems for Over 100 Years

For over 100 years **Croll Reynolds** has specialized in the design and manufacture of process vacuum systems. Croll Reynolds' line includes Steam Jet Ejector Systems, Combination Liquid Ring/Ejector Systems, Ejector Based Power Systems, Specialty Liquid and Gas Driven Ejectors, Thermocompressors, Vacuum Chillers, and Desuperheaters. Croll Reynolds supplies state-of-the-art vacuum systems for the Chemical, Petrochemical, Agricultural, Pharmaceutical, Power, Textile, Flavors and Fragrance, Paper, Aerospace, Steel and Food Processing Industries worldwide.

Croll Reynolds' Vacuum Equipment is utilized in a broad range of industrial applications including distillation, evaporation, crystallization, cooling, desalination, space simulation and steel degassing. CR has manufacturing, research and test facilities in the United States, and India and maintains sales and service facilities in the USA, Europe, Asia and South America. Croll Reynolds was established in 1917 in New York City by Samuel W. Croll and Philip E. Reynolds. The Company's headquarters are in New Jersey USA.

Croll Reynolds' ACHEMA 2018 booth is located at Hall 4.0 H4.

www.croll.com

Aerzen: Expect Performance

The company

Industrial plants all over the world are provided with gaseous media using **AERZEN** blowers and compressors. The innovative AERZEN machine technology represents experience of more than 150 years company history. The range of products includes rotary lobe compressors, positive displacement blowers, turbo blowers, screw compressors and gas meters. AERZEN blowers, compressors and gas meters are tested and certified according to DIN EN ISO 9001. There is a variety of product offerings from standard products to customised solutions.

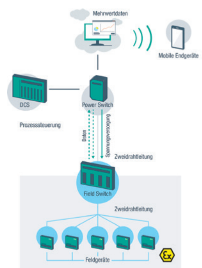
The key to your reliable and individual solution

When it comes to your best solution, you should be as uncompromising as we are: It must be precisely tailored to your requirements, absolutely reliable and highly efficient. With individual assembly configurations and customised services, AERZEN has been serving demanding process applications worldwide for over 150 years. Thanks to efficient compressors and blowers, comprehensive engineering knowledge and pronounced consulting competence, AERZEN can implement your individual customer requirements exactly. The unique AERZEN product expertise ensures you an efficient process solution and sustainable plant availability. In addition, the AERZEN After Sales Service offers the complete range of services - from the full maintenance contract to repairs and upgrade of existing plants.

www.aerzen.com

Condition Monitoring and Predictive Maintenance with Innovative Industry 4.0 Applications

Neoception Solutions Complement Pepperl+Fuchs Products



At Achema 2018, Pepperl+Fuchs will be demonstrating several possible applications for the realization of integrated communication from the field right through to cloud-based data platforms. In addition to its well-known and proven products, Pepperl+Fuchs offers an agile development partner for innovative IoT solutions in the form of its subsidiary, Neoception.

IIoT for Process Automation

As part of "IIoT for Process Automation," remote I/O from P+F is used to map field devices—such as control valves and flow measuring instruments—in existing plants, along with all relevant data, in the SAP Cloud Platform. The parallel transmission path is completely independent from the control system connection and therefore complies with the Namur Open Architecture framework.

www.pepperl-fuchs.com

Economic Indicators

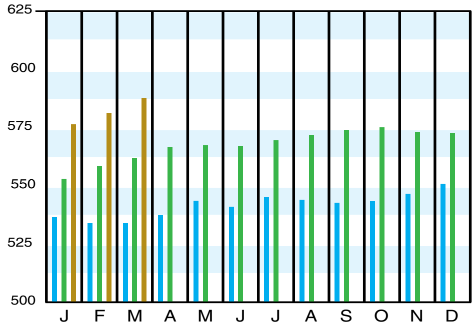
2016 2017 2018

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Mar. '18 Prelim.	Feb. '18 Final	Mar. '17 Final
CE Index	587.8	581.0	561.9
Equipment	712.7	703.3	676.6
Heat exchangers & tanks	624.9	616.2	590.9
Process machinery	702.4	700.3	672.1
Pipe, valves & fittings	930.4	903.6	863.7
Process instruments	418.1	416.9	403.2
Pumps & compressors	1017.7	1009.6	982.3
Electrical equipment	532.8	532.0	514.3
Structural supports & misc.	762.5	755.5	733.3
Construction labor	331.6	330.3	325.8
Buildings	582.2	576.5	555.1
Engineering & supervision	311.0	310.7	314.7

Annual Index:
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5

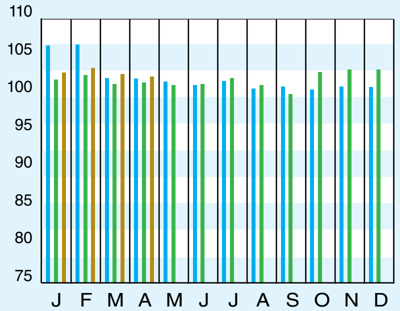


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

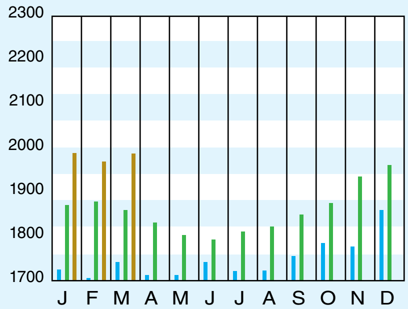
CURRENT BUSINESS INDICATORS

	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2012 = 100)	Apr. '18	=	102.3	Mar. '18	=	102.0	Feb. '18	=	101.8	Apr. '17	=	100.0
CPI value of output, $ billions	Mar. '18	=	1,988.8	Feb. '18	=	1,973.3	Jan. '18	=	1,991.2	Mar. '17	=	1,830.1
CPI operating rate, %	Apr. '18	=	76.2	Mar. '18	=	76.1	Feb. '18	=	76.0	Apr. '17	=	75.4
Producer prices, industrial chemicals (1982 = 100)	Apr. '18	=	265.8	Mar. '18	=	269.1	Feb. '18	=	274.5	Apr. '17	=	255.4
Industrial Production in Manufacturing (2012 =100)*	Apr. '18	=	104.1	Mar. '18	=	103.6	Feb. '18	=	103.6	Apr. '17	=	102.2
Hourly earnings index, chemical & allied products (1992 = 100)	Apr. '18	=	186.4	Mar. '18	=	189.8	Feb. '18	=	187.9	Apr. '17	=	177.5
Productivity index, chemicals & allied products (1992 = 100)	Apr. '18	=	95.8	Mar. '18	=	97.4	Feb. '18	=	95.8	Apr. '17	=	98.2

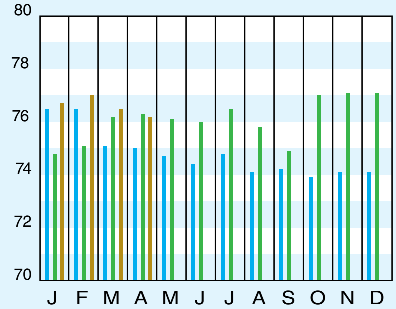
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the March 2018 *CE* Plant Cost Index (CEPCI; top; most recent available) increased compared to the previous month's value, continuing a string of monthly increases since the beginning of the year. And for the second consecutive month, all four of the subindices (Equipment, Buildings, Construction Labor and Engineering & Supervision) moved higher for March. The Equipment subindex had the largest month-to-month increase, percentage-wise. The overal CEPCI for March stands at 4.6% higher than the corresponding value from March of last year. Meanwhile, the Current Business Indicators (CBI; middle) showed a small increase in the CPI output index for April 2018.